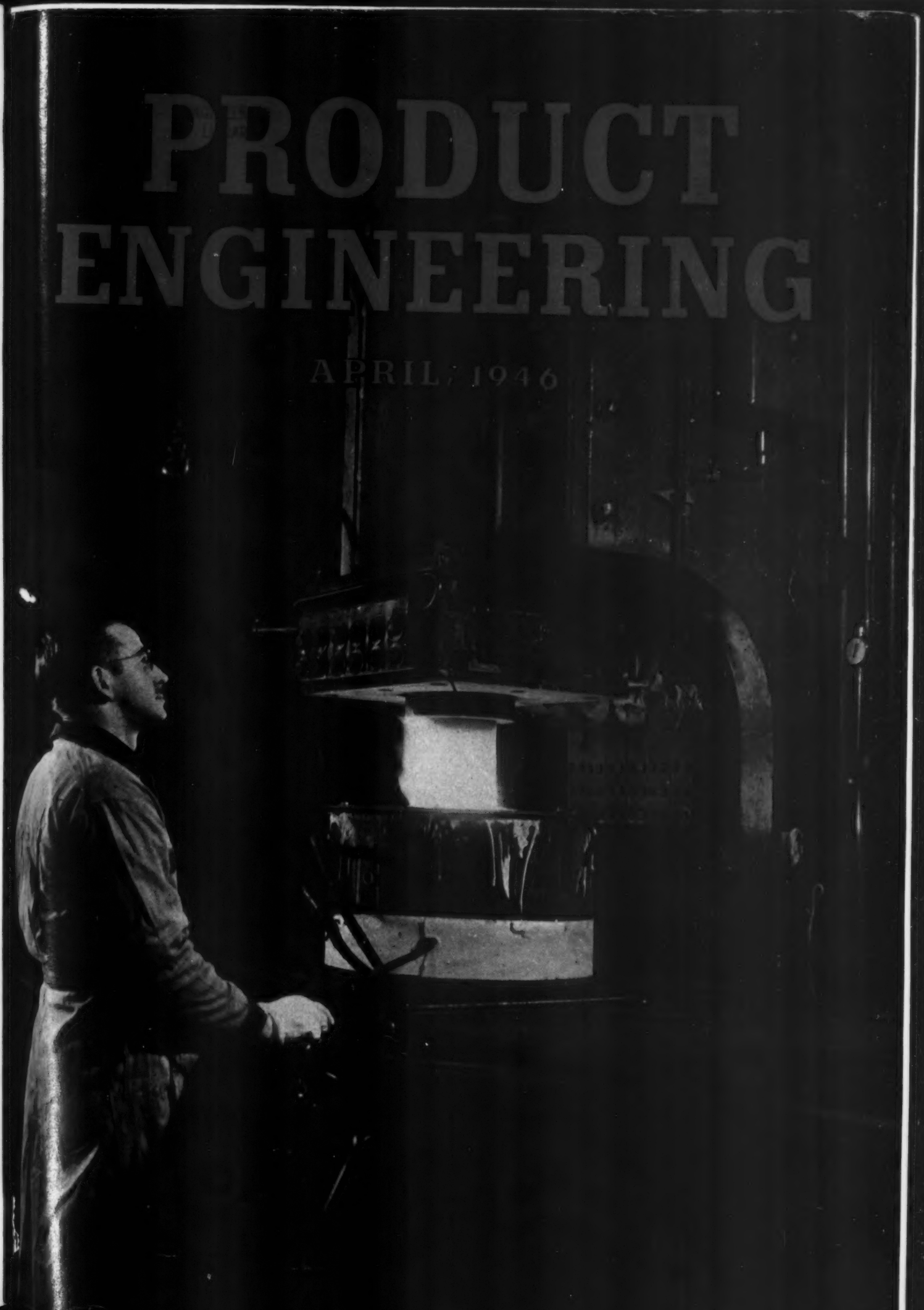
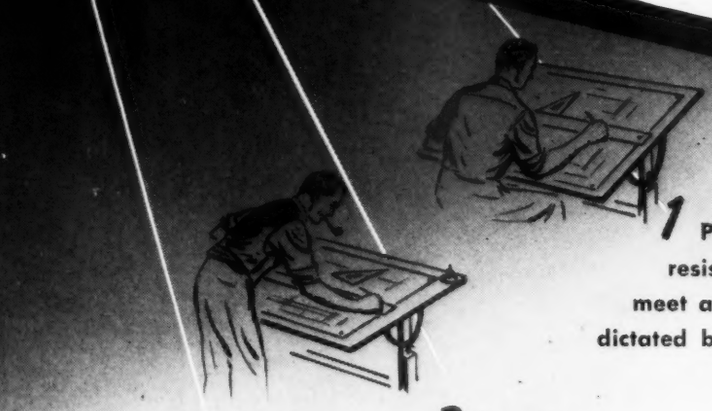

PRODUCT
ENGINEERING
APRIL 1946

Triple reasons for specifying...

TRIPLE ALLOY STEELS *containing* NICKEL



1 PERFORMANCE—Strength and toughness, resistance to wear, fatigue or shock to meet a wide range of requirements, as dictated by design.

2 RELIABILITY—based on consistently uniform response to heat treatment.

3 ECONOMY—resulting from standard compositions precisely graded to match the engineers' needs.

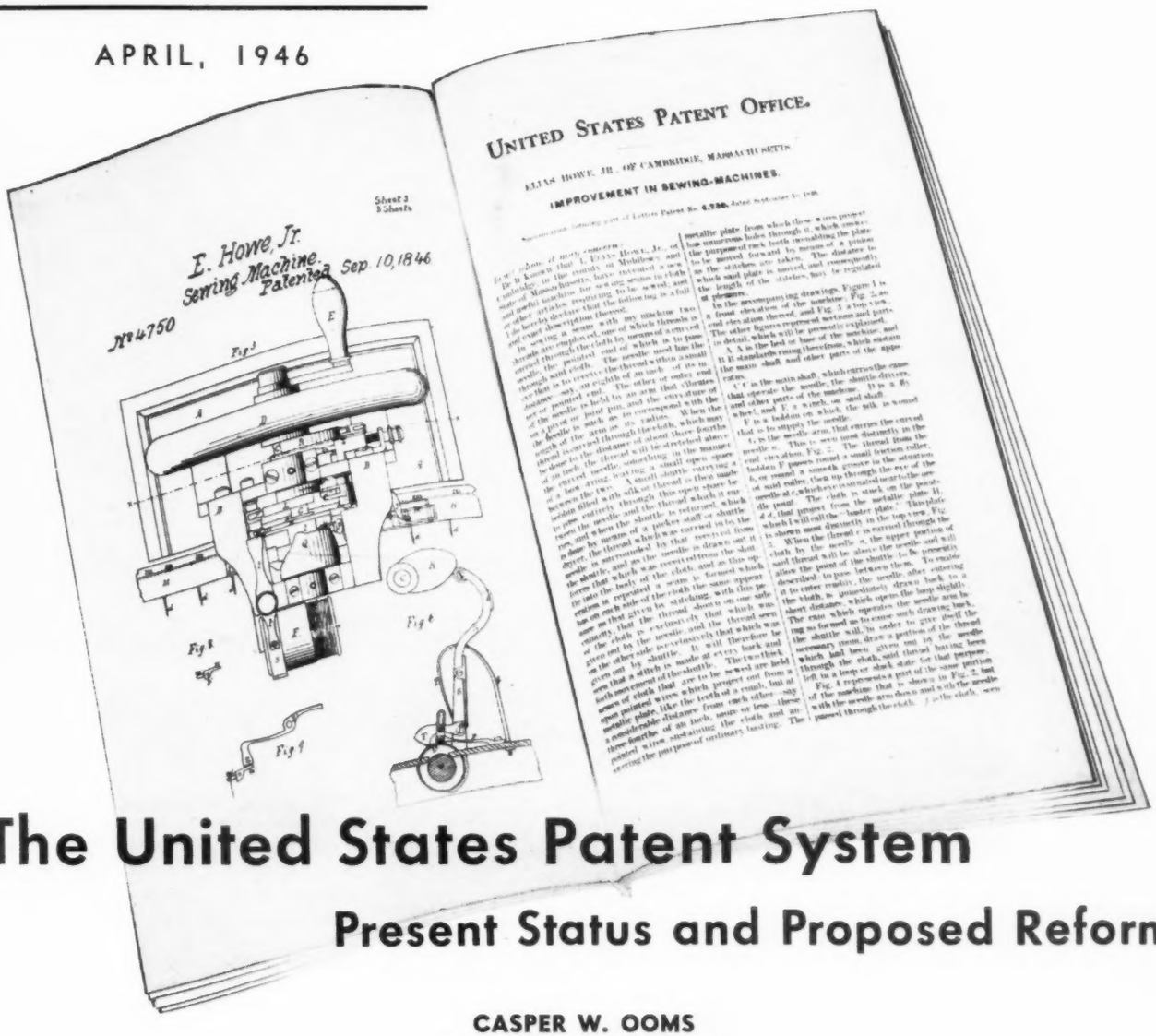
Experience shows that triple-alloy steels containing Nickel are solving some mighty big problems in many industrial fields. They have established outstanding service records in some of the most exacting applications. The many standard compositions available make it possible to select *accurately*, and with economy, triple-alloy steels to fulfill the requirements of a great variety of applications.

We invite inquiries regarding the selection and uses of triple-alloy steels, containing Nickel.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 Wall Street New York 5, N.Y.

PRODUCT ENGINEERING

APRIL, 1946



The United States Patent System

Present Status and Proposed Reforms

CASPER W. OOMS
Commissioner, U. S. Patent Office

THE VIGOR AND ENTERPRISE of the American industrial system is well reflected in the increased operation of our patent system. Never before in the history of the United States Patent Office has such a torrent of applications for patents on new ideas been pouring in. These applications represent accomplished development and invention. Another evidence of the increasing interest in new devices is the great activity in the Search Room of the Patent Office. There, minutely classified according to subject matter, are the two and one-half million patents heretofore issued by the United States Patent Office and the hundreds of thousands of patents issued in foreign countries. In the Scientific Library of the Patent Office are millions of publications which disclose accomplished technical advancements. Now in increasing number these technical resources are being examined for available material that might be translated into new business and advanced manufacture in the United States.

The growing interest in the technical development of this country is also evidenced in the greatly increased demand for copies of patents, which the Patent Office sells for the price of 10 cents. Each year millions of copies are sold; this sale has now reached a new weekly high of more than one hundred thousand copies.

These facts prove that the United States patent system has produced results that are useful and sought after by manufacturers, and are evidence also that the patent system works to accomplish its intended purpose. This primary purpose is expressed in the constitutional provision that the establishment of the patent system is "for the promotion of science and useful arts." More than two and one-half million patent applications have sucessfully matured into patents. This is further evidence that the Patent System has attracted into the Patent Office a large number—hundreds of thousands—of inventors who have offered to disclose their invention for the grant of a patent upon that invention. Thus, the primary purpose of the patent system, to obtain the completion and the publication

of an invention, is realized. Each year, in response to the reward thus offered to the inventor, from fifty to one hundred thousand applicants bring their patent applications to the United States Patent Office. As a result, between twenty-five thousand and fifty thousand patents per year are issued to those inventors. And each year more than twenty-five thousand patents expire, having run the seventeen years which constitutes the life of the patent grant. Upon the expiration of each of these patents the invention becomes available to anyone.

Advantages of Our System

The public, upon the completion of the seventeen year patent term, thus procures for itself the right to duplicate the disclosure in the patent grant. During the life of the patent, however, the patent serves an entirely different purpose. It assures the inventor that he alone may make and sell and use the thing that he has invented, disclosed, and claimed in his patent. To some people this means that the public is deprived of access to this invention. If each patentee took his patent, put it away, and did nothing to produce his invention, this might be true. But in fact the patent, with its exclusive grant to manufacture, often assures that the public will be supplied with the invention in greater volume and at lower prices than if the invention were free for all to copy. Often the invention covers some simple device, of which volume manufacture requires special and expensive tooling, which only the possessor of the exclusive license will undertake. One manufacturer given exclusive rights would invest in the special machinery needed. If the invention were available to a dozen manufacturers, each might make the article in small quantities and by inefficient processes; thus the total volume would be supplied at a greater cost.

Frequently a patent permits the small company to reach markets and to continue in business against odds and disadvantages to which larger competitors are not subject. Many small businesses have thus been able to grow into substantial factors in a competitive market, owing their success only to a patent that enabled them to operate at a time when their existence was doubtful.

Another benefit results from this exclusive right to employ an invention for seventeen years. If a manufacturer makes a bid for the exclusive market of his patent-protected competitor, his ingenuity for producing a better product is exercised. Thus, healthy competition, the lifeblood of American business, is stimulated. We see the result of this in the full yield of American industry, where the customer can go to many different sources and choose articles that are useful toward the same general end, but still satisfy different tastes and desires.

While the American patent system has been condemned because of abuses that are charged against it, those fundamental benefits inherent in it dictate that it continue. The United States Patent Office is as interested as any private organization in seeing that the patent system is strengthened and that its defects be eliminated.

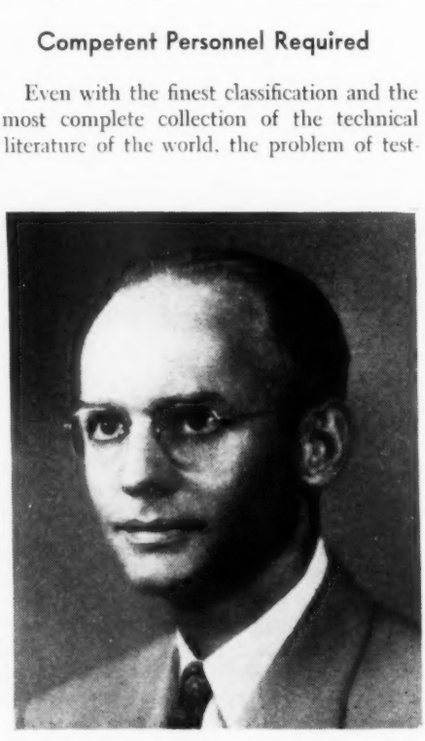
Abuses in the System

One criticism frequently directed against the patent system is that it results in the issuance of a large number of invalid patents. While the number may vary, it is inevitable that some invalid patents will be issued. The exercise of human judgment in any field will yield error. It is inevitable that some similar inventions escape the examiner's eye, since the technical literature available today discloses an extremely voluminous collection of inventions. In the first place, there is no complete collection of all of this literature anywhere in the world. It is important that some definitive collection of this material be made, and that the material be classified in such a way that it is readily usable. This is an important project, but one which is far beyond the efforts of the Patent Office alone. All of industry and science should be interested in seeing that some common catalog of the scientific and technical knowledge of the world would be formulated. This is a goal, furthermore, toward which all of the world must look.

Competent Personnel Required

Even with the finest classification and the most complete collection of the technical literature of the world, the problem of testing patent applications is only half solved. Ultimately, determination of the patentability of each invention must depend upon the exercise of human judgment by the examiner. With the increasing complexity of modern technical sciences, it is important that the examiner be a man of unquestioned competency and complete training. This requires that the qualification standards for patent examiners be continually re-examined and raised. It means that the Patent Office must attract to its staff personnel as competent as that demanded by any university, or any established laboratory. And the Patent Office in turn must offer present compensation and future rewards commensurate with the qualifications required.

For more than a hundred and nine years we have operated under what is substantially the same patent law. The procedure has not changed greatly in that period. It is important that every step in the examining process be evaluated against present-day requirements and that everything purely formal and unnecessary be eliminated, and that the practice of prosecuting a patent application be reduced to the most essential form. This means not only some alteration in the formal procedures in the Patent Office, but also an entirely new approach to the whole process of patent examination.



Recently appointed Patent Commissioner, Mr. Ooms is a native of Chicago, where he took his law degree. After general law training, Mr. Ooms engaged exclusively in the practice of patent law. He has lectured on patents before the Chicago Bar Association, Yale and John Marshall Law Schools.

Preventing Invalid Patents

The primary job of the Patent Examiner is to check the patent application against previous patents and literature in the field in which the invention occurs. There is some feeling that the examiner uses everything that occurs to him as a reason for refusal. We in the Patent Office are eager to see that attitude transformed so that the Patent Examiner looks upon his task as one of a public official entrusted with judgment on an important technical question; that he exercises his critical faculty to the utmost, but when he finds that there is substance to the invention, he helps the applicant find the most suitable method of expressing that invention. This alone should greatly shorten the time during which the patent application is processed in the Patent Office.

Another difficulty is disclosed by the large number of patents held invalid. The question of "invention," which must be determined before any patent application is permitted to issue, is exceedingly difficult to evaluate. Even the definition of the word invention has long exasperated those who have dealt with it. The courts have taken one view, the Board of Appeals in the Patent Office a slightly different view, and many examiners have still another impression. If the patent examination procedure is to be made most useful, these different standards of invention must be reconciled. Some commonly acceptable definition should be formulated, as a guide for each examiner

Washington Evening Star

Public search room at the Patent Office in the Commerce Department Building, where, patent lawyers have complained, crowded conditions are intolerable. Above is Trade Marks Division, located in the search room.

and tribunal dealing with the question.

We in the Patent Office are now occupied with the task of attempting to define invention, so that we can reduce the error in the process of judgment to the greatest possible extent. We hope thus to be able to issue patents that have a greater prospect of success when placed in litigation.

Prevent Invalid Patents

We are developing these new procedures in spite of the fact that the easiest way to operate the Patent Office, and the most profitable way from the standpoint of our immediate budgetary problem, would be to issue a patent to each applicant as quickly as possible. We know that the patent system's value to the public lies not in its immediate operating cost, but in so performing our function that few patents will be issued on which any real question of validity can be raised. We know that every invalid patent casts doubt upon every good patent issued by the Patent Office. An invalid patent costs the public more in the inhibition of industrial expansion and the cost of litigation, than the small cost of taking appropriate steps to prevent its improper issue.

There are other problems relating to patents in which the Patent Office is interested, although the primary responsibility for the correction of these difficulties lies with Congress and with industry itself.

The entire problem of patent litigation, because of its costliness and the long periods of delay before final determination of cases, has been the subject of a great deal of criticism. One method by which patent litigation may be expedited is to provide district judges with independent technical experts for advice on technical issues. Another device to shorten patent litigation is provided for in the Henry Bill, now before Congress, which would eliminate the necessity for ascertaining profits of an infringer in the determination of liability for infringement.

Compulsory Licensing

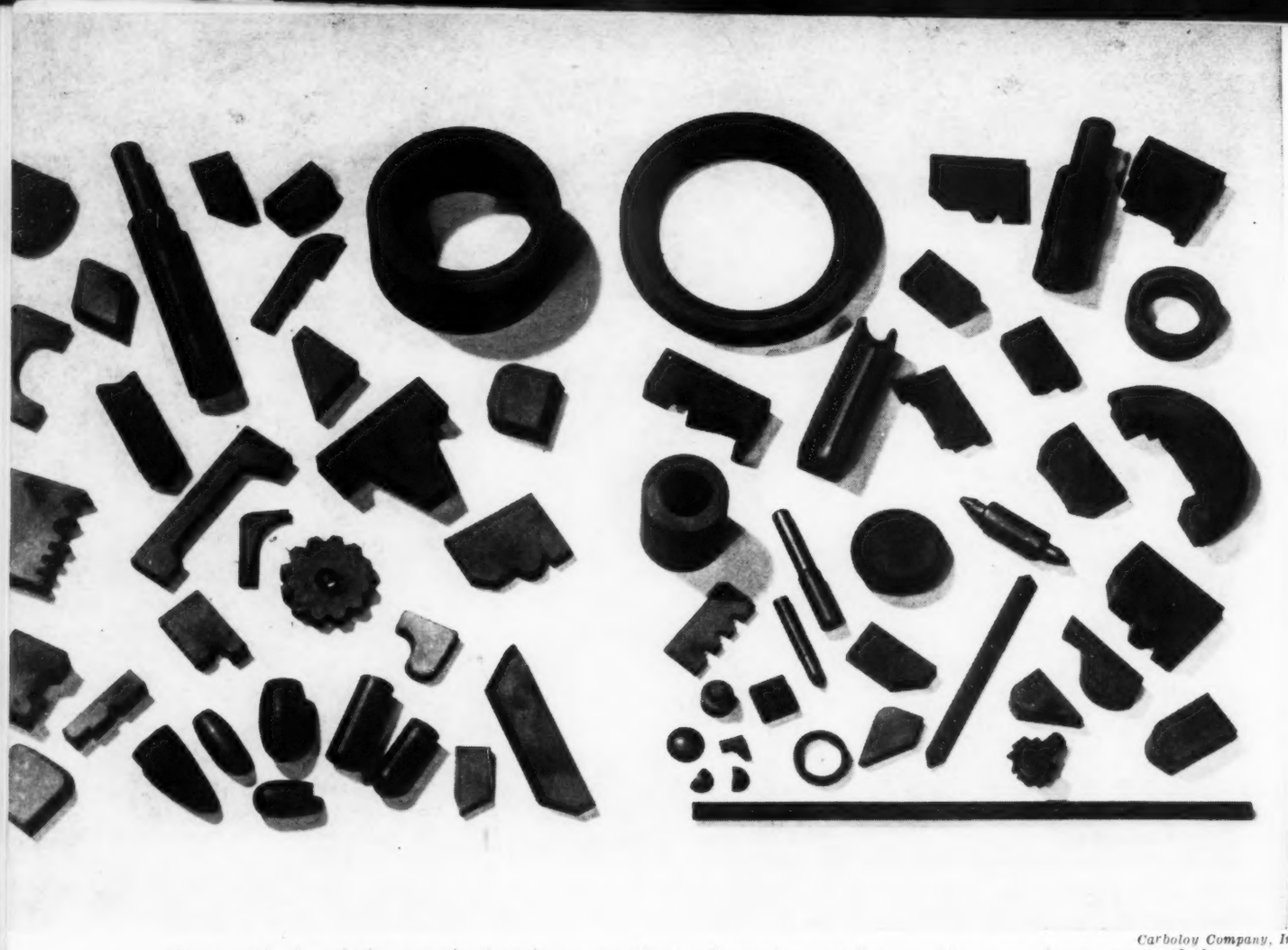
Many critics of the patent system have sought to establish compulsory licensing of patents to any applicant willing to pay reasonable royalties for the use of the invention. This expedient would eliminate one of the great incentives to invention in this country. The inventor would be aware that as soon as he has developed a new device he could not go into business to produce it alone. He must be willing to permit all of his competitors, many of whom would be established companies with many advantages, to produce the same thing at substantially the same or even less cost.

General compulsory licensing of all inventions would have the additional detriment of placing business under no compulsion to compete in the production of new devices. Everybody would thus leave the development work to his competitors and not undertake the hazards which inevitably accompany pioneering.

Public Interest

There may be situations, however, in which the public need is so great as compared with the desirability of promoting technical progress that some restricted form of compulsory licensing would be desirable. The National Patent Planning Commission has recommended this for fields in which the public health or safety is involved. There may be other situations in which a restricted form of compulsory licensing could be invoked. Where the public need is not being satisfied, because a patent is being suppressed or because the manufacturer chooses to make the patented article in insufficient quantities or to offer it only at exhorbitant prices, there might be some justification for public intervention. Most inventions can be made in alternative forms, so that such action would probably not be necessary.

Any law for compulsory licensing must be carefully drawn so that it does not deny the people of the United States the benefits of their patent system, by giving unearned advantages to those who do not experiment, and on the other hand that the patent system places no shackles upon the needs of the people.



Carboloy Company, Inc.

Fig. 1—Hard carbides are the best-known products of powder metallurgy. Here are shown some of the many parts made from carbides for use on highly stressed points for maximum hardness and wear-resistance.

Engineering Properties of Sintered Metals

PAUL SCHWARZKOPF
Director of Research, American Electro Metal Corporation

Powder metallurgy is the only commercial production method for a number of metals that possess unusual properties of hardness, porosity, heat resistance or other physical characteristics. Herein are given information relating to the three classes of sintered powdered metal pressings and 11 tables covering physical properties.

THE SINTERED and pressed powder metals that can be produced only by the powder-metallurgy method can be classified on the basis of their particularly outstanding property. On this basis the classifications are: high-melting point metals and alloys; high-hardness metals and alloys; and porous products. This however is not a rigid classification as there will always be properties in common. Also, the last classification, porous alloys, is not strictly a physical property classification derived from the properties of the material. Porosity in these alloys is a more or less mechanically produced structural condition obtainable in many of the materials.

Refractory Metals

This group includes tungsten, molybdenum, tantalum and columbium, which have melting points too high to permit application of conventional melting methods.

Tantalum can be fused in the vacuum arc but the products obtained are far inferior to those manufactured by sintering. The development of ductile refractory metals, initiating the renaissance of powder metallurgy in the first decades of this century, made possible the production of superior incandescent lamps and radio tubes, thus creating huge new industries. Other important applications of tungsten and molybdenum include X-ray electrodes, structural parts for high-

vacuum technique, heating elements, metal-to-glass sealing and electric contact materials. Table I gives the physical properties of tungsten and molybdenum.

Tantalum is used in high-vacuum electronic tubes as it can absorb and retain gases at high temperatures and low pressures. Properties are given in Table II. Other important uses are based on its remarkable resistance to corrosion, particularly acid corrosion. Tantalum and tantalum-coated materials are already widely used in chemical equipment, as blades for steam turbine nozzles, valves and diaphragms, as spinnerets for rayon spinning, fountain pens, and similar products. A comparatively recent development is the use of tantalum in surgery for the replacement of shattered bones or destroyed cartilage.

Columbium, so far, is mainly limited to parts in electronic tubes. However, the metal has only recently become commercially available in appreciable quantities and a considerable extension of its use can be expected, particularly since its resistance against acid corrosion is about as high as that of tantalum. Table III gives the physical properties of Columbium.

Tungsten and molybdenum form a continuous series of solid solutions, and these

Table I—Physical Properties of Tungsten and Molybdenum

	Tungsten	Molybdenum
Density, g. per c.c.		
compacted, unsintered	———	6.1–6.3
presintered	10.0–13.0	———
sintered	16.5–17.5	9.2–9.4
swaged	18.0–19.0	9.7–10.0
drawn	19.0–19.3	10.0–10.3
Melting point, deg. C	3,370	2,620
deg. F	6,100	4,750
Tensile strength, lb. per sq. in., hard drawn wire or rolled sheet, unannealed	250,000–600,000	200,000–350,000
annealed (recrystallized)	150,000	171,000
Elongation, percent		
unannealed	1–4	2–5
annealed	0	10–25
Modulus of elasticity, lb. per sq. in	60,000,000	50,000,000
Brinell hardness		
sintered bar (18 by 18 mm.)	200–250	150–160
swaged to 5 mm	350–400	———
1-mm. sheet	———	250–255
Linear coefficient of expansion, per deg. C	0.0000046	0.0000047–0.0000058
Electrical resistivity, microhms per c.c.	4.8	5.5

Table II—Physical Properties of Tantalum

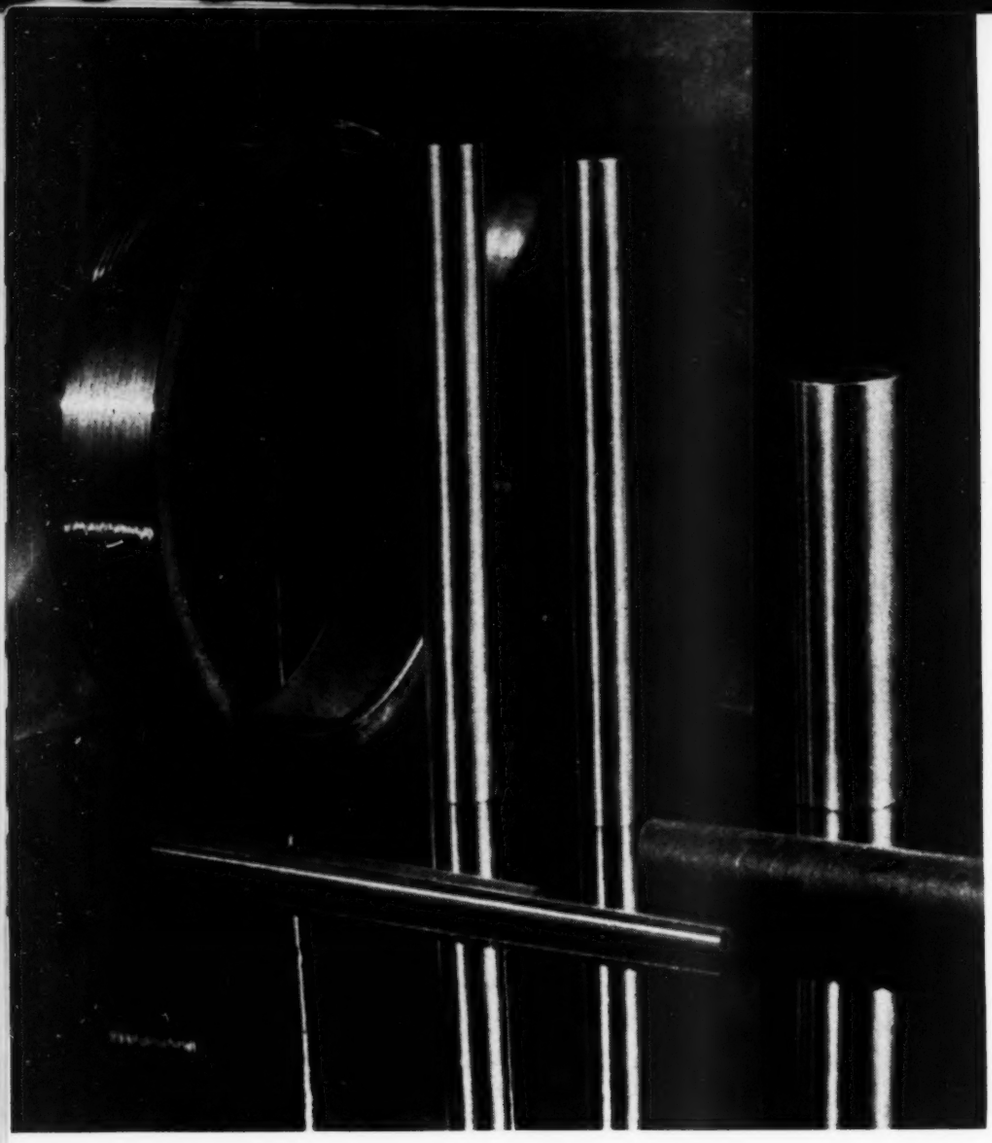
Density, g. per c.c	16.65
Melting point, deg. C	2,850
deg. F	5,160
Tensile strength, lb. per sq. in.	
worked	125,000–170,000
annealed	50,000–75,000
Elongation, percent	
worked	2–3
annealed	25–40
Modulus of elasticity, lb. per sq. in	27,000,000
Brinell hardness	45–600
Linear coefficient of expansion between 20 and 500 deg. C., per deg. C	6.6×10^{-6}
Thermal conductivity, cal. per sq. cm. per cm. per sec. per deg. C.	
between 20 and 100 deg. C	0.13
at 1430 deg. C	0.174
at 1830 deg. C	0.198
Electrical resistivity, microhms per c.c.	
at 20 deg. C	15.5
at 1430 deg. C	71
at 1830 deg. C	80

Table III—Physical Properties of Columbium

Density, g. per c.c	8.57
Melting point, deg. C	2,415
deg. F	5,150
Tensile strength, lb. per sq. in.	
worked	85,000
annealed	42,500
unannealed wire (tentative)	96,000–130,000
annealed sheet (tentative)	48,000–59,000
Elongation, percent	
worked	2
annealed	10
Brinell hardness	
worked (unannealed)	200–250
Linear coefficient of expansion between 0 and 100 deg. C., per deg. C	7.2×10^{-6}
Specific heat, cal. per g	0.036
Electrical resistivity, microhms per cu. cm. at 20 deg. C	14.1

Table IV—Physical Properties of Tungsten-Molybdenum Alloys

Composition, percent		Melting point		Density (worked) g. per c. c.	Electrical resistivity at 20 deg. C., microhms per c.c.	Temperature coefficient of electrical resistivity, between 20 and 100 deg. C.	Brinell hardness
Mo	W	deg. C.	deg. F.				
100	0	2,620	4,750	10.3	4.8	4.75×10^{-3}	200
72.5	27.5	2,675	4,850	12.8	8.3	3.25×10^{-3}	250
51	49	2,850	5,160	14.8	9.0	2.9×10^{-3}	300
20	80	3,075	5,570	17.5	8.0	3.2×10^{-3}	330
0	100	3,370	6,100	19.3	5.5	4.82×10^{-3}	350



Molybdenum and tungsten bars, wires and sheet.

alloys, see Table IV, are widely used as supporting material in incandescent lamps and electronic tubes.

Tungsten and molybdenum alloys with additions of tantalum and columbium have a higher electrical resistance than the pure metals, and their application as resistor heating elements appears promising.

Of special interest are the systems tungsten-nickel-copper and molybdenum-tungsten-copper, the so-called "Heavy Metals" or "Heavy Alloys," the properties of which are given in Table V. These products are used for applications requiring high absolute densities, such as containers for radioactive substances, screen materials for radioactive radiation and X-rays, also to balance crankshafts of aircraft engines, to balance controllable-pitch airscrews, or centrifugal clutch plates providing the slipping mechanism for supercharger drives and the like. The density of these alloys exceeds that of lead but is lower than that of pure tungsten. However, pure tungsten of maximum density cannot be produced, at present, in pieces of large size.

Tungsten and molybdenum alloys with 5 to 10 percent nickel can be produced with a specific gravity up to 17.0 but this requires sintering temperatures exceeding the melting point of nickel (1,450 deg. C.; 2,650 deg. F.). The addition of copper lowers the melting point so that lower sintering temperatures can be employed.

Although originally developed as high-density materials, "Heavy Metals" possess, as shown in Table V, remarkable strength and electrical properties, which resulted in further uses for these alloys. Compositions with maximum tensile strength and elongation are used, for instance, for rotors in gyroscopes and gyrocompasses. Because of their resistance against material transfer, combined with relatively high electric conductivity and great hardness, they are utilized in electrical contacts where the effects of high currents and wear must be resisted. In the light of probable developments in atomic energy utilization, the most important attributes of "Heavy Metals" appear to be their screening properties against radioactive radiation.

Sintered Alloys of Exceptional Hardness

Hard metals—or cemented carbides—consist of metal carbides, particularly tungsten, titanium and tantalum carbides, with a metal of the iron group, particularly cobalt, as "binder." The characteristic properties of the hard metals are due to the high inherent hardness of the carbides at elevated temperatures and to the high mechanical strength imparted by the action of the binder metal. Properties are given in Tables VI, VII and VIII. Diamond, corundum, silicon carbide, and boron carbide surpass the hardness of

Table V—Compositions and Properties of Various "Heavy Metal" Alloys

Alloy No.		A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Composition, percent	W	90	90	90	90	84	84	84	84	76	76	76	76
	Ni	7	5	3	1	11	8	5	2	16	12	8	4
	Cu	3	5	7	9	5	8	11	14	8	12	16	20
W/Ni Ratio		12.9	18	30	90	7.6	10.5	17	42	4.8	6.3	9.5	19
Ni/Cu Ratio		2.33	1	0.43	0.11	2.2	1	0.45	0.14	2	1	0.5	0.2
Sintering Temp., deg. F.		2,510	2,425	2,375	2,265	2,510	2,425	2,375	2,265	2,510	2,425	2,375	2,265
Theoretical Specific Gravity		17.6	17.6	17.6	17.6	16.9	16.9	16.9	16.9	16.2	16.2	16.2	16.2
Specific Gravity after Sintering		13.6	13.3	14.3	13.6	13.1	12.8	14.2	13.2	12.4	11.8	13.9	13.2
Density after Working and Annealing		16.6	16.5	16.7	16.6	15.5	15.4	15.6	15.6	15.0	14.4	14.6	14.5
Elec. Conductivity percent, I.A.C.S.		16.5	17	17.5	19	13	14.2	15.5	17	9.8	11.5	13.3	15.4
Tensile strength, 1,000 lb. per sq. in.		60	86	105	78	84	93	93	68	96	90	78	60
Brinell Hardness		213	218	238	248	208	214	214	208	170	220	185	176

Table VI—Properties of Tungsten Carbide—Cobalt Compositions

Co. percent	Specific Gravity	Hardness, Rockwell A (60 kg. load)	Transverse Rupture Strength, lb. per sq. in.	Compressive Strength, lb. per sq. in.	Impact Strength (Charpy), ft.-lb.	Young's Mod. of Elasticity lb. per sq. in. x10^{-6}	Thermal Conductivity*	Coefficient, Thermal Expansion†	Electrical Resistance, Ohms per m. per sq. mm. at 20 deg. C.
3	15.25 15.04	91.0–93.0 —	125,000 170,000	— 815,000	— —	— 97.5	— 0.19	— —	— 0.213
4.5	15.05	92.3	200,000	890,000	—	90.5	—	—	—
6	14.7 14.85 14.82 —	90.0–92.0 — — —	205,000 234,700 225,700 227,500	680,000 730,000 604,000 750,000	0.73 — — —	88 89 — —	0.19 0.21 — —	5.0x10^{-6} — — —	0.211 0.20 0.21 —
8	—	85–89	—	—	—	—	0.21	5.0x10^{-6}	0.20-0.25
9	14.56	88.5–91.0	—	685,000	—	—	—	—	0.223
11	14.0	—	263,000	540,000	—	82	—	5.5x10^{-6}	0.18
13	14.10 14.15	87.0–89.5 —	300,000 —	540,000 625,000	1.10 —	80 —	0.652 —	5.9x10^{-6} —	0.196 —
20	12.54	85.0–87	350,000	550,000	1.75	—	—	—	—

* Cal. per cm. per sec. per deg. C. † Average over range 20 to 700 deg. C. (68 to 1,290 deg. F.)

Table VII—Properties of Tungsten Carbide—Titanium Carbide Compositions with Cobalt Additions

Carbide Composition	Co percent	Specific Gravity	Hardness, Rockwell A, 60 kg. load	Transverse Rupture Strength, lb. per sq. in.	Compressive Strength, lb. per sq. in.	Impact Strength, ft.-lb.	Coefficient Thermal Expansion*
1) Predominantly WC + TiC	8	12.80	91.5 to 92.5	250,000	720,000	0.60	—
2) Predominantly WC + TiC	13	12.80	89.8	250,000	—	—	—
3) Predominantly WC + more TiC than 2)	13	11.95	90.0	240,000	—	—	—
4) Predominantly WC + more TiC than 1)	6	11.20	92.0 to 93.0	160,000	700,000	0.40	6.8x10^{-6}
5) Predominantly WC + more TiC than 3)	13	10.10	90.0	180,000	—	—	—
6) Predominantly WC + more TiC than 4)	7	9.0	92.0 to 93.0	150,000	725,000	—	7.0x10^{-6}

* Average range 20–700 deg. C., 68–1,290 deg. F.

Table VIII—Properties of Tungsten Carbide—Tantalum Carbide—Titanium Carbide—Cobalt Compositions

Grades, carbide compositions, percent	Co percent	Density	Hardness, Rockwell A, 60 Kg. load	Transverse Rupture Strength lb. per sq. in.	Compressive Strength lb. per sq. in.	Impact Strength (Charpy) ft.-lb.	Young's Modulus of Elasticity, lb. per sq. in. x10^{-6}	Thermal Expansion, Average Range 20–700 C. (68–1,290 F.)	Thermal Conductivity, cal. per sq. cm. per cm. per sec. per deg. C.
Predominantly WC, TaC, TiC	8	11.7	91.5–92.5	165,000	720,000	—	72	6.75x10^{-6}	—
Predominantly WC, TaC, TiC	11	11.6	90.5–91.5	175,000	680,000	0.60	—	6.0x10^{-6}	—
Predominantly WC, TaC, TiC	15	11.4	89.5–90.5	190,000	670,000	0.92	67	7.5x10^{-6}	—
Kennametal KH: 62.9 W, 9 Ta, 9.4 Ti KM: 55.5 W, 13.6 Ta, 10.2 Ti KS: 62.2 W, 14.3 Ta, 4 Ti	 10.1 10.7 10.8	 — — —	 91 90.3 89.9	 224,000–280,000 275,000–350,000 310,000–373,000	 690,000 — —	 — — —	 — 58 —	 — — —	 0.075 0.110 0.120

cemented carbides, but in many applications, cemented carbides, because of their greater toughness, perform better than the three harder materials.

Hard metals are widely used in tools, and are also employed for dies and similar parts requiring high wear and corrosion resistance. The longer life of carbide tools and the greater cutting speeds possible played an important part in the armament program. Of special importance were the materials containing two or more carbides in solid solution which permitted 10 to 50-fold increase in the speed of cutting steel.

A class of pressed powdered metal compositions containing refractory metals have been developed especially for contact materials. They contain, in addition to the refractory metal, a constituent of high electric conductivity, such as silver or copper. They combine electrical conductivity with resistance to high temperatures, mechanical wear and the detrimental effects of arcing. The components of these materials are not

alloyed, the composition being a physical mixture and thereby the favorable characteristics of each of the original materials is retained fully in the composition. Only powder metallurgical techniques permit the manufacture of such composite contact materials, irreplaceable for high-duty applications. Table IX summarizes the characteristics of typical representatives of this class.

An interesting tungsten-silver multilayer contact material has recently been described by H. H. Hausner in PRODUCT ENGINEERING, September 1945, page 618. Other composite contact materials include those of the systems Ag-Ni and Ag-Cd. Pure refractory metals and hard metals are also suitable contact materials. Pure tungsten contacts are in use for high-voltage applications, while hard metals are used in the polar relays designed for telegraph systems.

One of the oldest applications of powder metallurgy is the manufacture of copper-graphite brushes for current transfer between moving and stationary parts of electrical equipment, such as motors, generators, and rotary converts. These products are typical representatives for the class of metal-nonmetal combinations, which also includes friction materials and bonded diamond tools.

Current-carrying capacities of copper-graphite brush materials depend on the graphite content, increasing from about 70 amp. per sq. in. for mixtures containing close to 70 percent graphite, to 125-250 percent for products containing not more than 5 percent graphite. The high-metal compositions permit momentary loads to 500 amp. per sq. in. The specific resistance of copper-graphite brushes varies between 50 x 10^{-5} and 0.4 x 10^{-5} ohms per sq. inch; the transverse strength between 2,500 and 25,000 lb. per sq. inch; and the scleroscope hardness between 5 and 35.

Porous Powdered Metal Pressings

Commercially, the most important products of this class are porous bearings which, by impregnation with oils, become self-lubricating. The tensile strengths of various porous bearing materials are compared with that of dense bronze bearing material. Porous parts are now being used also for filters. Table X gives the strength and density of four typical porous materials.

Proper sintering techniques, permitting a high degree of control of porosity, have made possible a number of important applications. The most interesting example of such uses appears to be the mercury switch which, as a safety device, is an essential part of the famous proximity fuze developed by the Navy. This safety device consists of a small porous nickel cup which is filled with mercury. The mercury, part of a short circuit, prevents current from reaching the detonator of the fuze. After firing, the spin of the shell forces the mercury through the porous bottom of the nickel cup and thus permits the radio equipment to operate and finally to explode the shell. The safety of the artillery crew depends on the exact timing, that is to say, on the speed with which the mercury permeates the porous metal; thus it actually depends on the degree of porosity of this material. The official Navy release states that the sintered cups "represent probably the highest degree of control ever achieved in the field of powder metallurgy." An official in the laboratory in charge of the development of the proximity fuze stated that, without the sintered nickel cups, "we might not have been able to supply the Navy with the material which kept the fleet operating off Okinawa, to name but one instance which might be cited." Data illustrating the degree of porosity and the reproducibility achieved in the production of the nickel cups cannot yet be revealed.

Filter materials that are resistant to high temperatures and corrosion have also been produced by the controlling of the porosity of the pressed and sintered material. The porosity of these filters is rated, as given in Table XI by the largest dimension of the smallest particles that are prevented from passing through the filter.

It can be expected that the experiences gained in the development of the porous nickel cup will be utilized to make further improvements of tolerances in the porosity of other products, including (in addition to filters and diaphragms) catalysts, electrodes for secondary elements, anodes for electrolytic cells, contacts and collectors, gaskets, clutch plates, printing types, and casting mold material.

Table IX—Physical Properties of Composite Contact Materials

Composition	Mo-Ag	W-Ag	W-Ag
Density	10	13.2	15.2
Conductivity (percent I.A.C.S.)	50	59	38
Brinell hardness	120–135	105–115	170–190

Table X—Strength and Density of Bearing Material

Bearing Material	Tensile strength, lb. per sq. in.	Density g. per c.c.
Dense bronze	21,000	8.6
Porous bronze	2,800–4,200	6.0–6.5
Porous iron	7,100–21,000	5.0–6.5
Porous Fe-Pb-graphite	17,000–21,000	5.5–6.0

Porous nickel cups, made by powder pressing, used in the proximity fuze as part of the safety device.

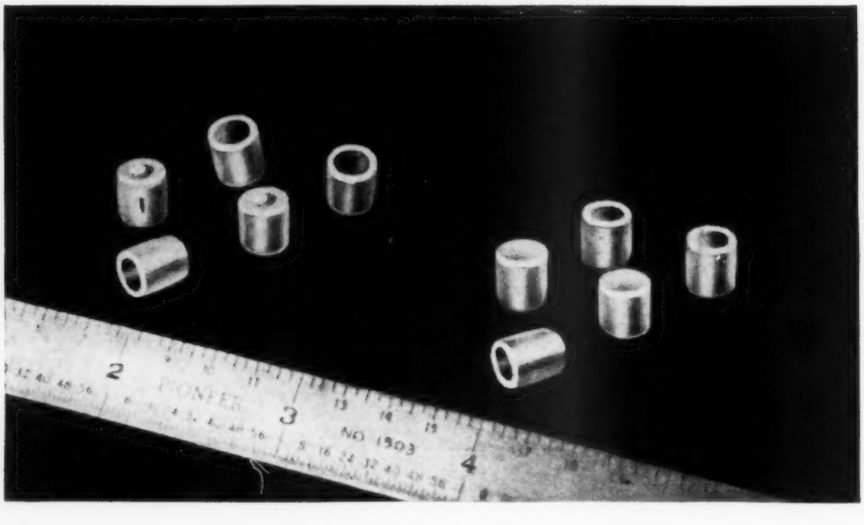


Table XI—Particle Stoppage by Bronze Porex Filters

Grade	Largest Particle Dimension, in.
1	0.002 to 0.005
2	0.001 to 0.002
3	0.0005 to 0.001
4	0.000 to 0.0005

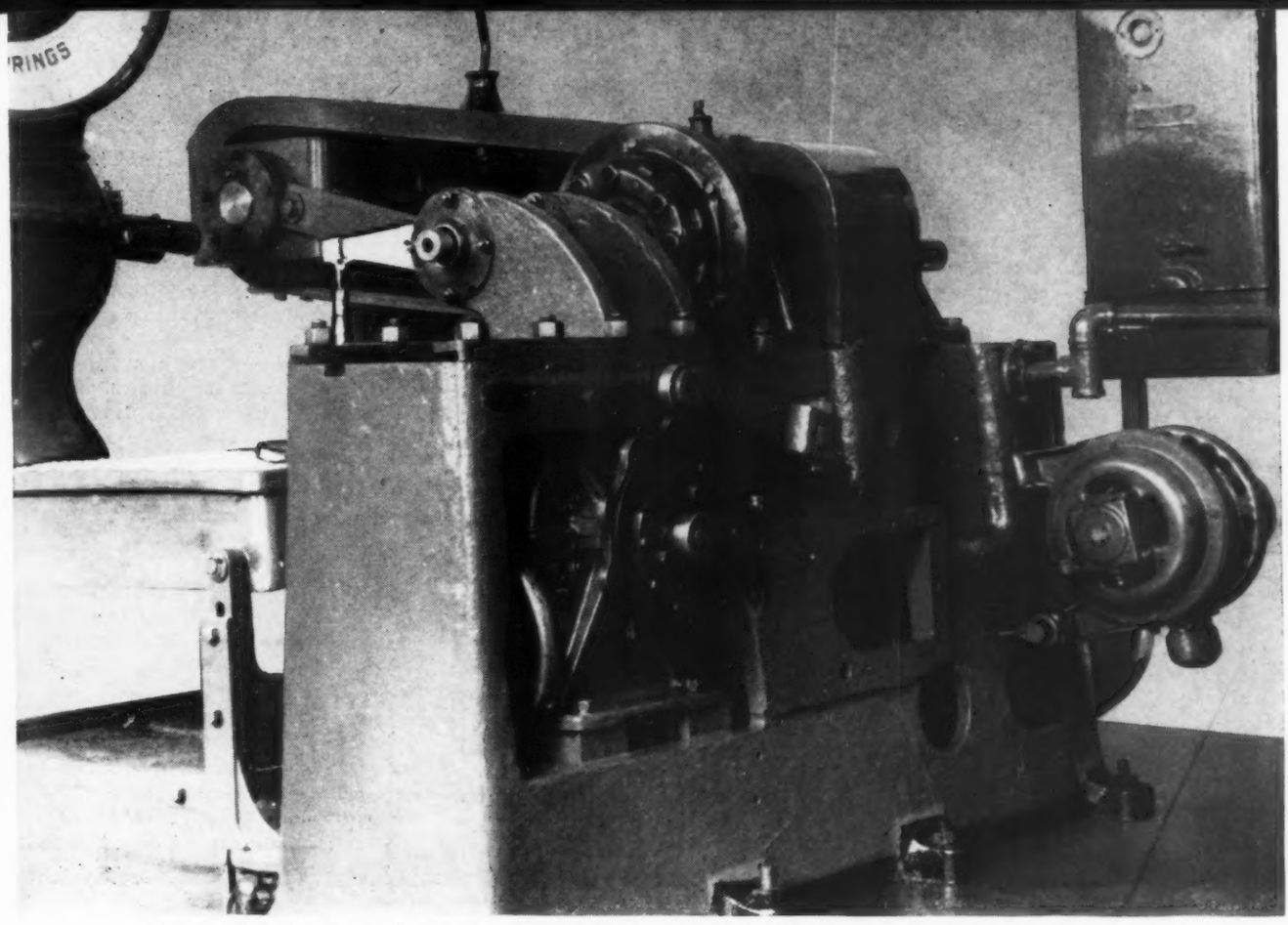


Fig. 1—A spring-loaded dynamometer for determining the friction coefficients of clutch facings. The clutch is slipped continuously for 90 sec. and torque is recorded at 5-sec. intervals.

Woven and Molded Friction Materials For Disk-Type Clutches

HAROLD NUTT
Director of Engineering, Borg & Beck Division of Borg-Warner Corporation

Woven and molded friction materials are discussed and tests to determine burst strength, coefficients of friction and wear characteristics described. Typical test data are given along with limiting test values between acceptable and inferior materials. The importance of road tests of automobile clutch materials is also discussed.

THE PURPOSE of this article is to describe how clutch facings are evaluated by means of physical tests in the laboratory and on the road.

Clutch facings in common use at the present time are made of an asbestos base compounded with various materials that serve as fillers and binders to give frictional and heat-resisting characteristics. Often a small amount of metal, usually in the form of brass chips or wire, is distributed throughout the mixture. The facings may be made of yarn woven into whole cloth and die cut, or they may have a circular weave of which there are several successful varieties. In either style the construction of modern facings is such that the rings are endless. This has been found helpful in raising their resistance to centrifugal bursting. The material may be cured in sheets between heated plates or in molds that are oversize to allow for grinding.

Although woven facings are frequently cured in molds, the term "molded" facings is commonly applied to non-yarn materials resembling fibre boards. There are two common types. In one type an asbestos millboard is built up to the desired thickness on a special paper machine. The slabs thus formed are dried, die cut into oversized rings, impregnated and cured. During a part of this process, pressure may be applied to give the required density. This method uses no molds.

Another type of molded facing is actually cured in a mold. Dry or wet mixtures are prepared and measured amounts are poured into the mold cavity after which pressure and heat are applied. Curing time and technique vary, depending on materials.

The result is that molded and woven facings that are die cut from sheets are available as well as molded and woven facings

that are made in molds. The trade and the public, however, are accustomed to speaking of woven facings as those made of yarn and of molded facings as those made of materials other than fabric. This accepted nomenclature will be used in the paragraphs which follow.

The foundation of most friction materials is organic. They are therefore subject to destruction by heat at comparatively low temperatures. Unfortunately, high temperatures are frequently generated at the friction surfaces. This is a primary cause of rapid wear.

In an effort to make friction materials less affected by heat, inorganic materials are introduced into the mixtures. As a rule, large percentages of such materials have been troublesome, causing abrasion of the surfaces against which the facings operate. Maintaining sufficient physical strength has also been a difficulty.

Some success has been achieved in the problem of heat resistance by the use of sintered metal mixtures containing a rather high percentage of copper. Such facings have been successful when operated in oil and are being used to a limited extent in dry clutches. They can be subjected to substantially higher temperatures without disintegration, but generally require higher spring pressures because of lower friction coefficients.

Another facing of the molded variety is semi-metallic. It consists of a mixture of asbestos and binders with a large percentage of copper particles. Although higher in cost than the regular woven or molded facings, the improved durability of this material in certain types of operation justifies the additional expense.

Burst Test

For the purpose of eliminating road tests on materials that may be inferior, the following laboratory procedure has been established: Sample facings, generally of a size regularly used in large quantities, are first subjected to a centrifugal bursting test. The rings are mounted on a standard clutch driven plate. The assembly is then soaked at 500 deg. F. in an electric oven for fifteen min. after which it is transferred to a bursting machine. The speed of the machine increases from zero to a maximum or about 12,000 r.p.m. at a pre-determined rate. Failure by centrifugal explosion may occur anywhere between 6,500 and 12,000 r.p.m. in acceptable materials. This range applies to rings about 10 in. in diameter.

If failure occurs at a speed below 6,500 r.p.m., no further laboratory tests are conducted and the material is classed as not suitable for passenger car or truck service. Lower bursting speeds are permissible in other applications as, for example, tractors and industrial trucks. The driven disk sometimes rotates at speeds exceeding maximum engine r.p.m. when the vehicle is coasted down hill in low gear with the clutch released. In trucks where the overall gear ratio is large the factor of bursting strength becomes paramount. For such service special high strength facings have been developed.

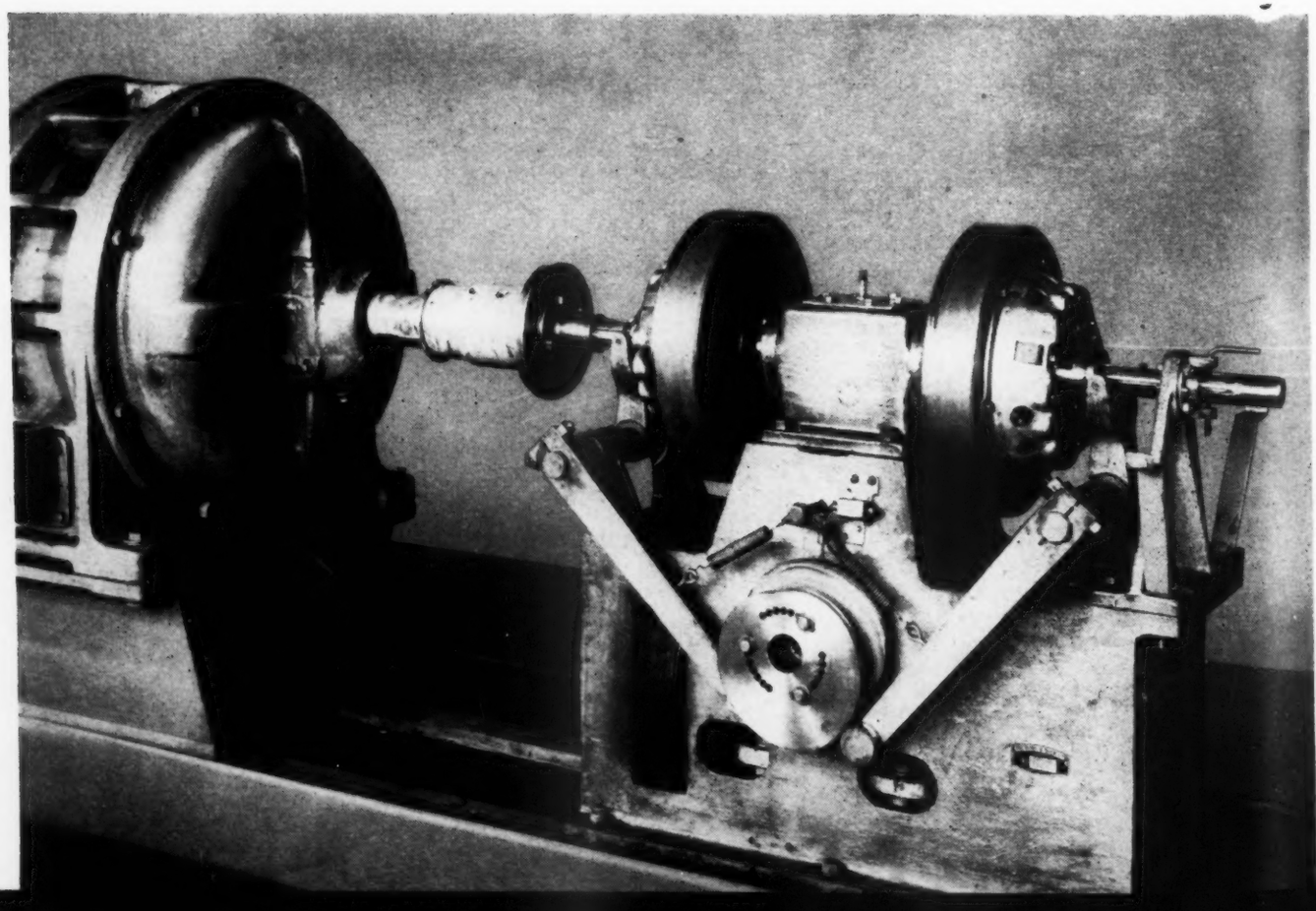
Following the burst test, the facings are checked for friction. The disk assembly is mounted on a dynamometer in a clutch having a calibrated spring load. The disk transmits torque to a one-foot arm resting on weighing scales, Fig. 1, while the flywheel and cover assembly are rotated at 1,125 r.p.m. Slip is continuous for 90 sec. The torque is recorded on a long sheet at five-sec. intervals. This is a severe test since the clutch is developing torque about equal to that for which the clutch is designed and the period of slip is 1½ min. The usual duration of slip to make a full throttle start of an automobile in low gear seldom exceeds two sec. or, for a start in second gear, about four seconds.

During this test, the friction of good materials will ordinarily be maintained for about 60 sec. After 60 sec. smoke usually appears and a fade or substantial loss of friction is to be expected for the remaining 30 sec. The final coefficient of friction should not be below 0.2 if reasonable reserve capacity for severe clutch service is to be available. Maximum readings at or near the start of the test are usually within the limits of 0.35 and 0.28 for the friction coefficient.

At least two driven plates of each material are tested on the friction machine. If the facings have a suitable friction range and do not soften, blister or warp, they are ready for the wear test. The same test specimens are used in the wear machine without dismounting them from the clutch disks.

The machine for the wear test consists of two flywheels mounted on a single shaft, which is carried on ball bearings, Fig. 2. The accelerating clutch and one of the disks

Fig. 2—Wear dynamometer tests two samples simultaneously, one in the accelerating clutch on the motor shaft and the other in the brake clutch, which does not rotate. Cam mechanism alternately engages and disengages both clutches.



BORG & BECK
DIVISION OF BORG-WARNER CORPORATION

CLUTCH FACING FRICTION FADE & WEAR TEST

Material & Size: 10 x 6 x .125" SAMPLES OF APRIL 20, 1945

(1) SEC.	(2) FADE TEST PRE-WEAR #1 FT. LB. TORQUE	(3) FADE TEST PRE-WEAR #2 FT. LB. TORQUE	(4) FADE TEST POST-WEAR #1 FT. LB. TORQUE	(5) FADE TEST POST-WEAR #2 FT. LB. TORQUE
0	145	168	133	117
5	148	163	132	123
10	150	163	143	126
15	150	166	152	132
20	147	174	147	136
25	160	175	151	139
30	156	176	152	142
35	162	172	152	144
40	184	172	148	146
45	193	177	159	154
50	184	174 S		
55	184 S	170		
60	189	164		
65	184	165		
70	174	168		
75	173	170		
80	167	163		
85	160	155		
90	154	147		
Max. f	.378	.354	.318	.308
Min. f	.290	.294	.264	.234

(6) WEAR TEST	(7) DRIVING CLUTCH	(8) BRAKE CLUTCH
Initial Thickness P. P. Facing	.399	.330
Final "AFTER" FADE	.336	.327
Wear on P. P. Facing AFTER WEAR	.323	.306
Initial Thickness F. W. Facing		
Final " " "		
Wear on F. W. Facing		
Loss	.013	.021
Total Wear Both Facings		
Total Wear Per 1000 Eng.	.0013	.0021
Average Wear Per 1000 Eng. Both Clutches .0017		

Condition Pressure Plate

BRAKE TORQUE COLD 190#
1000 ENGAGE. HOT 240
7000 ENGAGE. HOT 252
8000 ENGAGE. HOT 250
9000 ENGAGE. HOT 234
10,000 ENGAGE. COLD 182

Remarks: FACINGS REMAINED IN GOOD CONDITION AFTER FINAL TEST

Remarks: SMOKE STARTED AT 50 SECONDS. BECAME DENSE AT END OF TEST. GOOD STABLE FRICTION

Conducted By AM Date 4-27-45 Test No. 5347

FADE TEST: Continuous slip for 90 seconds at 1125 R. P. M. constant speed 750# plate load.
WEAR TEST 10000 engagements at 1200 R. P. M. 6 per minute 810# plate load.

Fig. 3—Chart showing typical data from friction and wear tests of a clutch material. Maximum and minimum coefficients of friction are tabulated below the fade test data in columns (2) to (5), from tests before and after wear.

is mounted on one flywheel. The other flywheel carries the brake clutch disk. An electric motor supports the accelerating clutch disk on an extension of the armature shaft. The brake clutch disk is mounted on a splined shaft, which is held stationary so that the disk can not rotate. Cams and a clutch-control linkage operate each clutch independently of the other and in sequence. The electric motor rotates at constant speed of 1,175 r.p.m. As the accelerating clutch engages, the flywheels are brought from rest to full speed in a slip time varying from 1½ to 2 sec. depending on the friction of the facings.

After the flywheels are up to speed, the accelerating clutch disengages. The brake clutch, which is disengaged during acceleration, now engages, bringing the wheels to rest also in 1½ to 2 sec. This clutch then releases to complete one cycle and to permit engagement of the accelerating clutch for another cycle. The test is continuous at the rate of six cycles per minute. A full test of 10,000 engagements can be completed in about 27 hours.

At the end of the wear test, the thicknesses of the facings are compared with the thicknesses before the test. Total wear of the two facings on each disk should be in the neighborhood of 0.002 in. per thousand engagements. Excellent facings may wear as little as 0.001 in. Wear of 0.004 in. indicates poor material.

At the end of the wear test, the fade test is repeated but for a 45-sec. period instead of 90 sec. The shorter duration of the final fade run is to prevent complete breakdown of the friction surface, which in some specimens makes difficult a study of the true condition of the material after the three tests. It is intended that both the fade and wear runs be abusive but not to the extent that the test specimens are destroyed.

A chart showing the results of typical fade and wear tests is shown in Fig. 3. Columns (2) and (3) show the torque on each of the two driven plates for the 90-sec. fade run. Columns (4) and (5) cover the readings obtained after the wear test. In columns (7) and (8) are shown the thickness readings of the driven plates before and after the wear test. An average wear rate of 0.0017 in. per thousand engagements is indicated. The rate on the driving disk was 0.0013 in. and on the driven disk 0.0021 in. Although in this case the brake disk wore at a slightly faster rate than the driving disk, such is not always the case. Nearly equal work is performed by the two clutches, which start and stop the inertia wheels; consequently, the rates of wear are reasonably uniform.

Stopping torque observations are made during the wear test after 1,000, 7,000, 8,000, 9,000 and 10,000 engagements, Fig. 3. These readings are taken to discover any marked change in friction that may develop during the wear test.

Road Tests

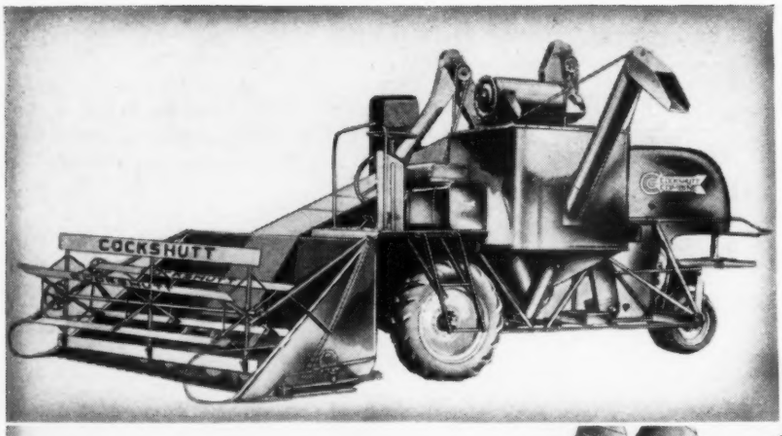
When samples have shown in the laboratory that they possess sufficient centrifugal strength and are within reasonable limits for friction and wear, they are ready for road tests. Installations are then made in a variety of automobiles and in as many cars of each kind as are available. Preliminary road tests are run by the clutch manufacturer, but final acceptance of the material is generally determined from the results of a fairly extensive series of road tests by the car manufacturers.

Great distances need not be traveled during the road tests, but it is important that the tests include all kinds of operating conditions. Clutch facing durability can be fairly well established in the laboratory, but clutch action can be accurately evaluated only on the road.

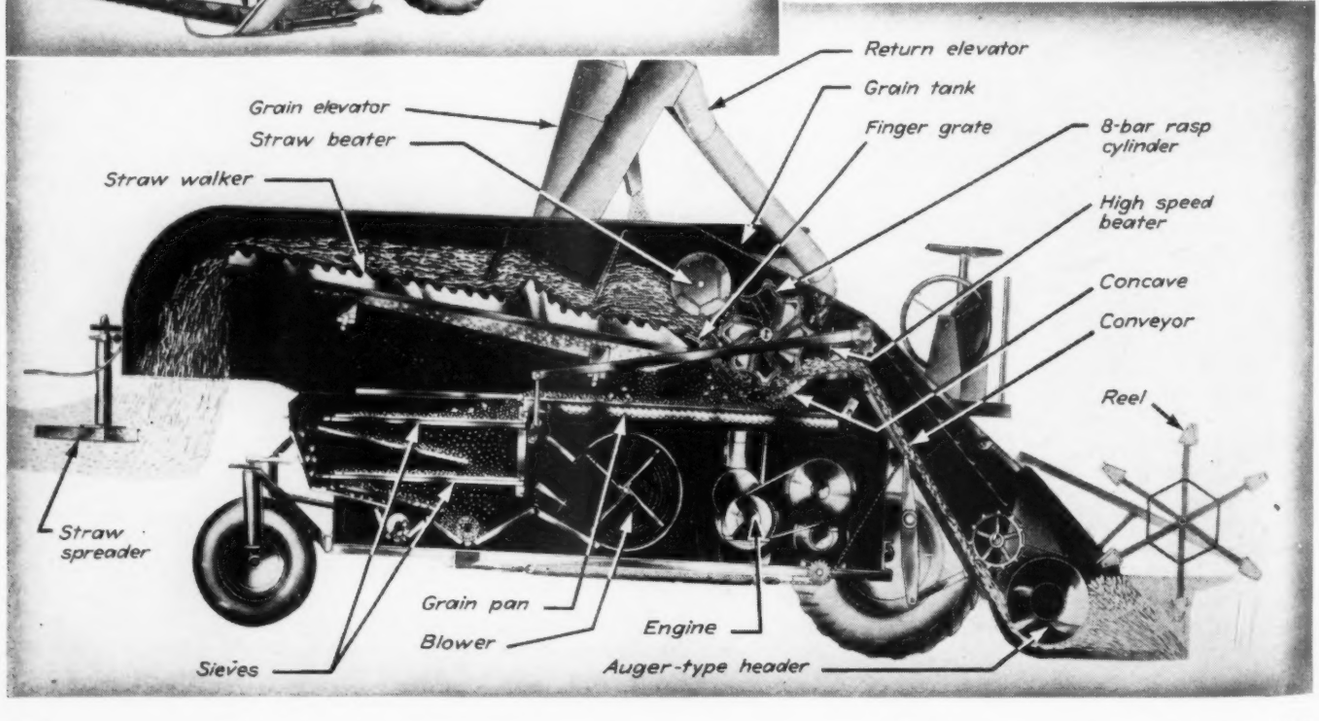
Troubles with clutch chatter and drag are more prevalent in hot than in cool weather. It is therefore important that some testing be carried out during the summer months or on cars in southern areas. Dampness is also troublesome. Many facing materials absorb a certain amount of water when the humidity is high. A condition that exists between the water-sensitive friction material and the adjacent surfaces of the flywheel and pressure plate can cause chatter on damp days. Certain facings also have a tendency to adhere to the friction surfaces after the car has been allowed to stand for some time during a damp spell. This may prevent release of the clutch. Elimination of water sensitivity is therefore highly desirable.

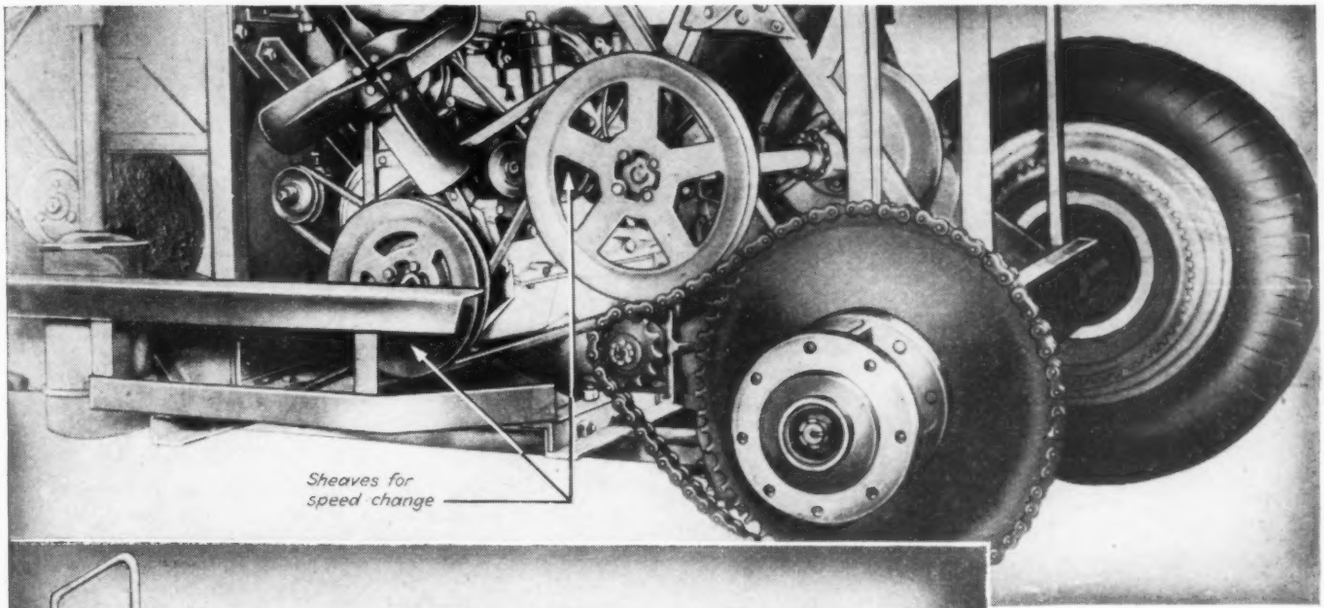
PRODUCT DESIGNS

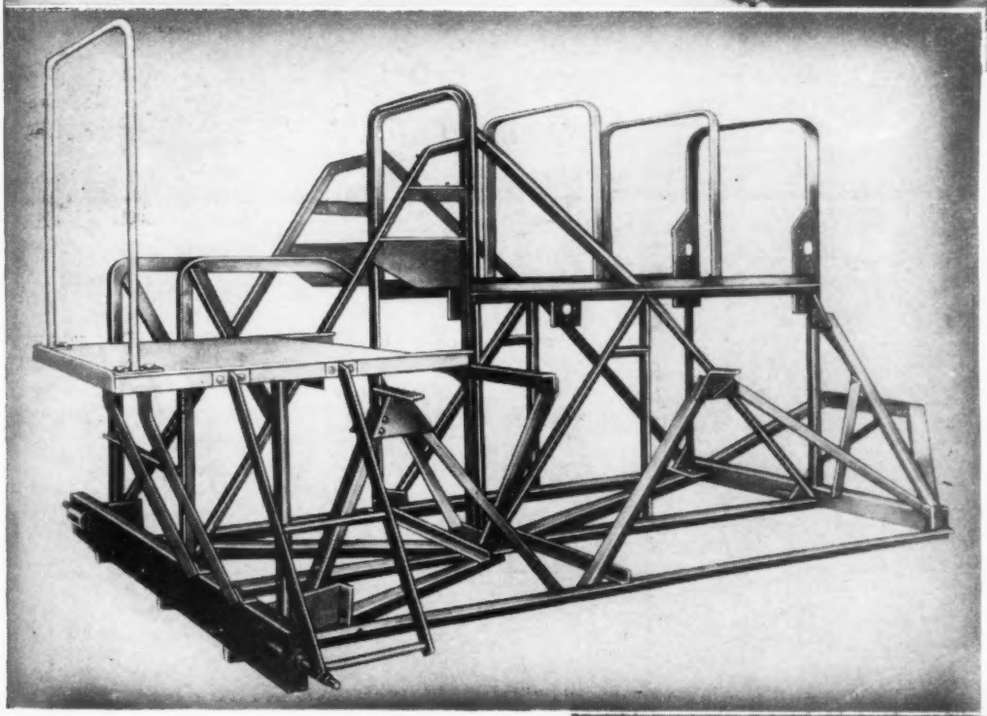
One Man Self-Propelled Combine Of Welded Steel Construction



ONE MAN OPERATION is possible in the new self-propelled combine developed by the Cockshutt Plow Company Limited of Brantford, Canada. Known as the SP112 Harvester Combine, the design allows the operator a clear view of the crop and cutter bar as well as control of traction and threshing mechanisms. Central mounting of the header results in an overall width less than a pulled combine of equivalent cutting width. This allows easier transport along narrow roads and through gates. No grain is lost on the opening cut and the machine is adaptable to strip farming and working along fences and ditches.







Combine is powered by a heavy-duty 6-cylinder, 60 hp. industrial motor. Located in the lower part of the combine, behind the driving wheels, the motor is easily accessible for minor adjustments and removable for overhaul.

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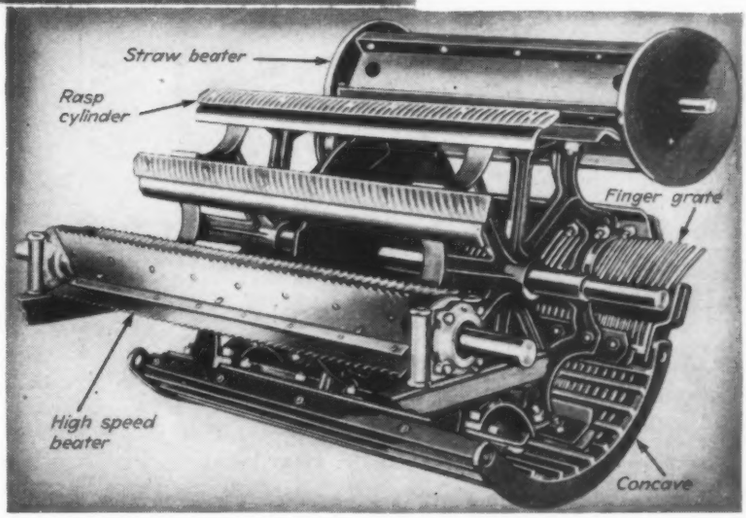
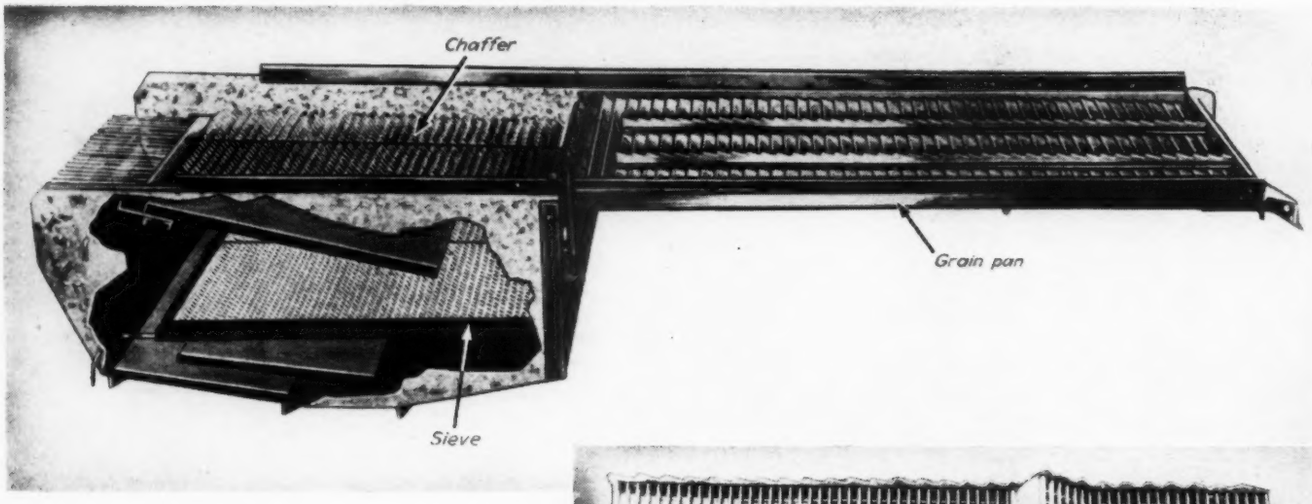
Frame is of bridge-type, electrically welded construction. Heavy reinforced channel axles support the frame and assure rigid alignment of all moving parts.

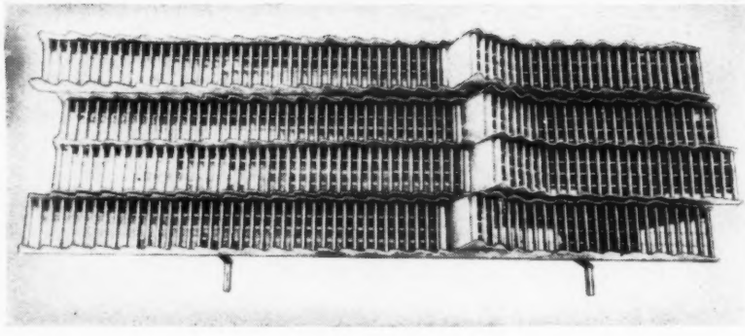


Even distribution of grain into the cylinder is maintained with a 4-blade, high speed beater. Rasp cylinder can be adjusted independently of the rest of the separating unit. Straw beater, mounted behind the cylinder runs at half the cylinder speed and retards the straw and allows unseparated grain to fall on the grain pan. Straw beater distributes straw to the straw walkers.

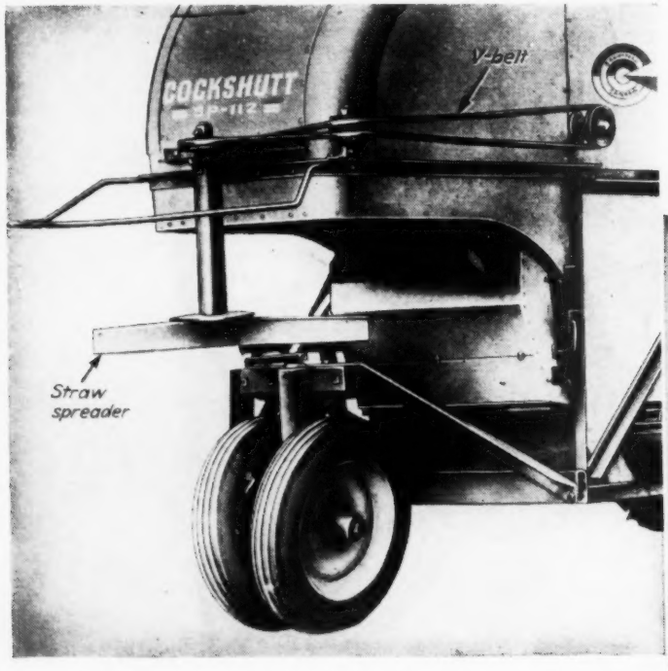
Combine (continued)



Grain pan extends in front of the concave allowing all grain coming from the cylinder and finger grate to separate from the chaff and fall to the bottom of the pan. Grain is then ready to go through the chaffer the moment it is reached. Between the chaffer and sieve is a return grain pan that delivers the grain and remaining chaff to the front of the adjustable grain sieve.

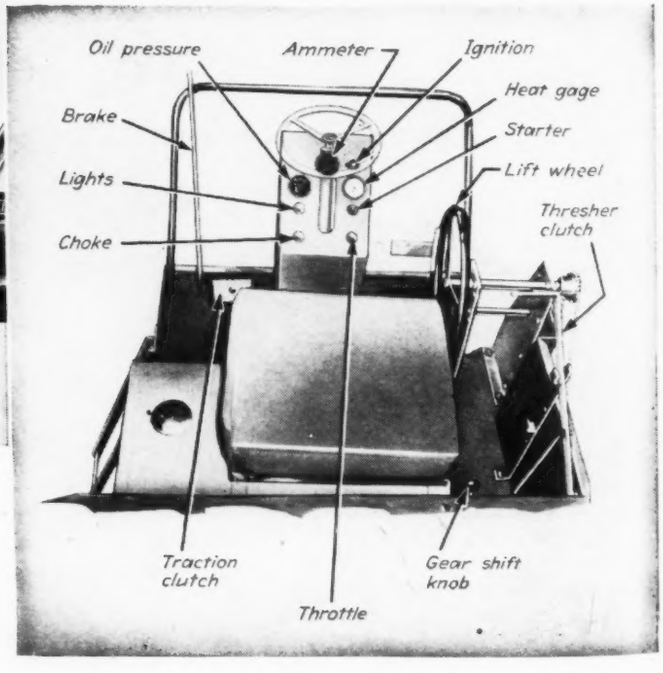


Straw walkers are of steel construction and are mounted on carefully balanced forged steel crankshafts. Crankshafts run in anti-friction bearings and the straw walkers are mounted on large oil-soaked maple bearings. The straw walkers rotate alternately and can be adjusted independently of the combine.



Tricycle rear steering allows quick and easy maneuvering. Straw spreader is driven through a V-belt.

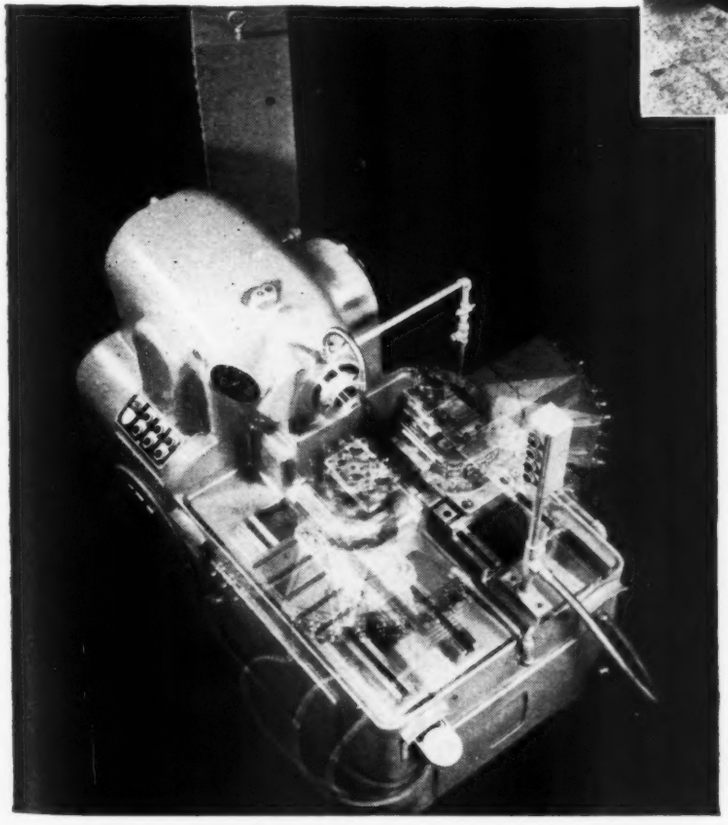
Operator's platform is large and is so located that all working parts of the combine can be viewed. All controls are conveniently located with all instruments mounted in a panel on the steering column.

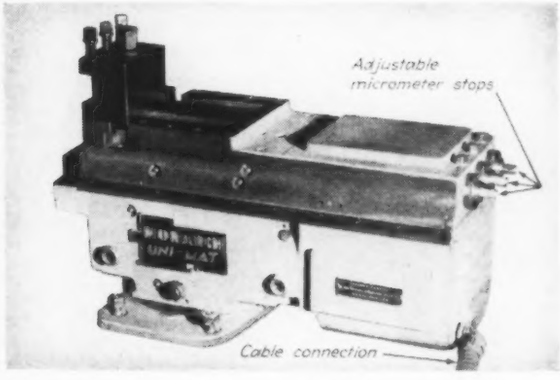


Automatic Quantity Production Lathe Has Individual Motor-Driven Tool Slides

LATHE DESIGNED for single-purpose large quantity production can be applied with slight alterations in electrical control, to small quantity production. Designed and developed by the Monarch Machine Tool Company the machine is known as the Uni-Matic Lathe. Machine consists of two members; a simplified conventional lathe base and headstock and from one to three individual motor driven tool slides mounted on tee-slotted bases. Tool slides, called Uni-Mats, are basically motor-driven compound rests that can be grouped about the spindle in an arrangement to best facilitate the application of the cutting tools to the work. Uni-Mats are connected to Uni-Matic Lathe by a cable. Separate electrical control cabinet contains all electronic and electrical equipment and is easily accessible for maintenance and inspection.

Machine setup time is reduced by the flexibility of the Uni-Mat slides. Each slide can be adjusted and setup without relation to the other slide or slides. Interlocked electrical timers are used to control the cycle relation between the individual slides. Should one Uni-Mat require repairs it can be replaced by a spare unit, thus preventing long down time for repairs.

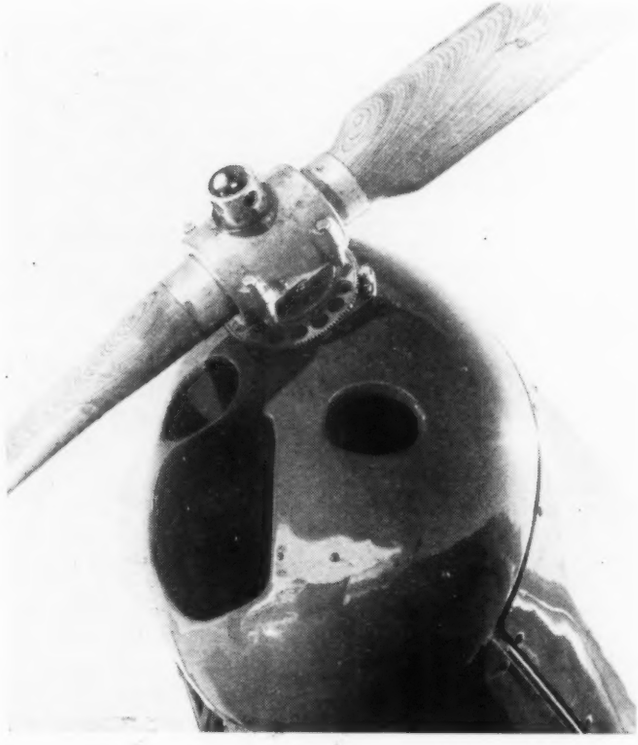


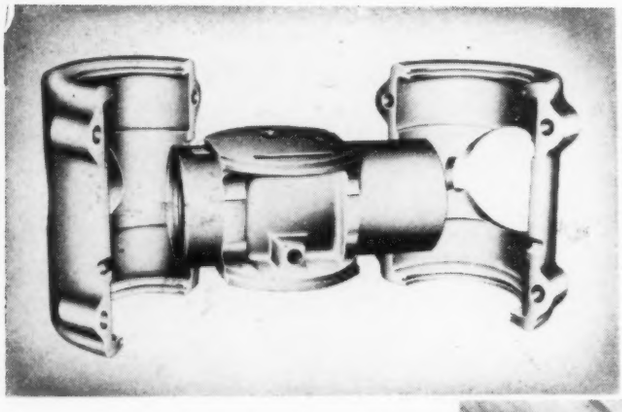


Uni-Mat is equipped with an electrically controlled a.c. or d.c. motor that traverses the main slide at 100 in. per min. until automatically slowed to a predetermined feeding rate for the remaining part of its total travel of 4 in. Amount of feed is controlled by three adjustable micrometer stops. Rate of feed is determined by sets of change gears giving feeds from 1/2 in. per min. to 13 in. per min. Slides are of two types, one equipped with tool relief and the other with a solid top slide.

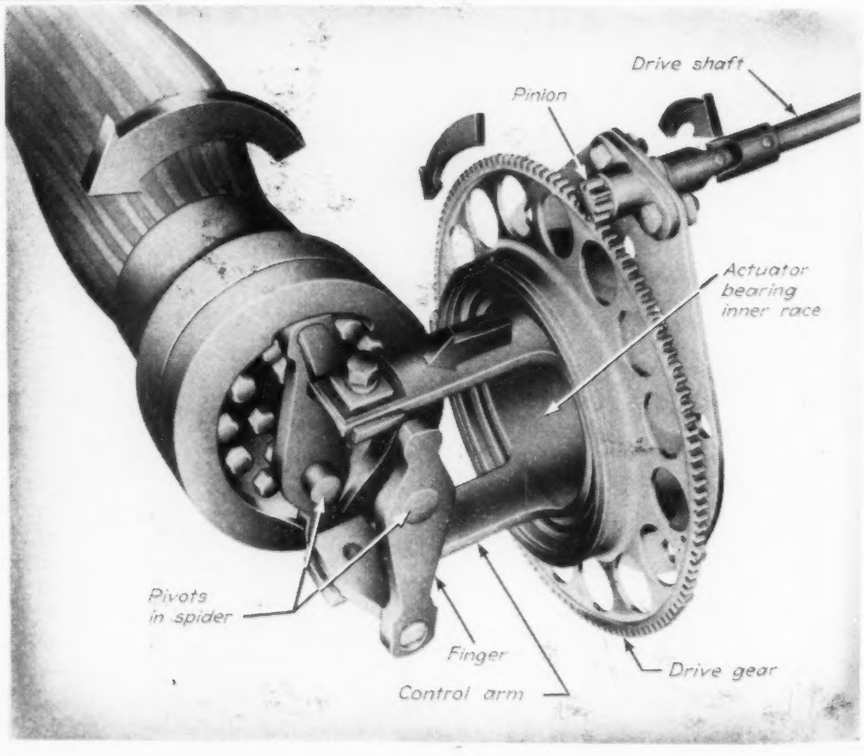
Controllable Pitch Aircraft Propeller Has Few Moving Parts

DESIGNED for controllable pitch and equipped with steel tipped, laminated wood blades is a new propeller developed by the Beech Aircraft Corporation and licensed under Roby patents. Control mechanism is simple, has few moving parts, and operation does not require that the engine be running. Propeller blades are mechanically controlled by arms located inside the propeller hub. Arms are actuated, through a gear and pinion drive, by a compact electric motor. Mechanism is controlled by a toggle switch located in the pilot's compartment. Blade position indicator, to show the blade angle, is available as optional equipment but is not required. Propeller is adaptable to both radial and opposed type engines developing up to and including 225 hp. weight is approximately 52.5 pounds.



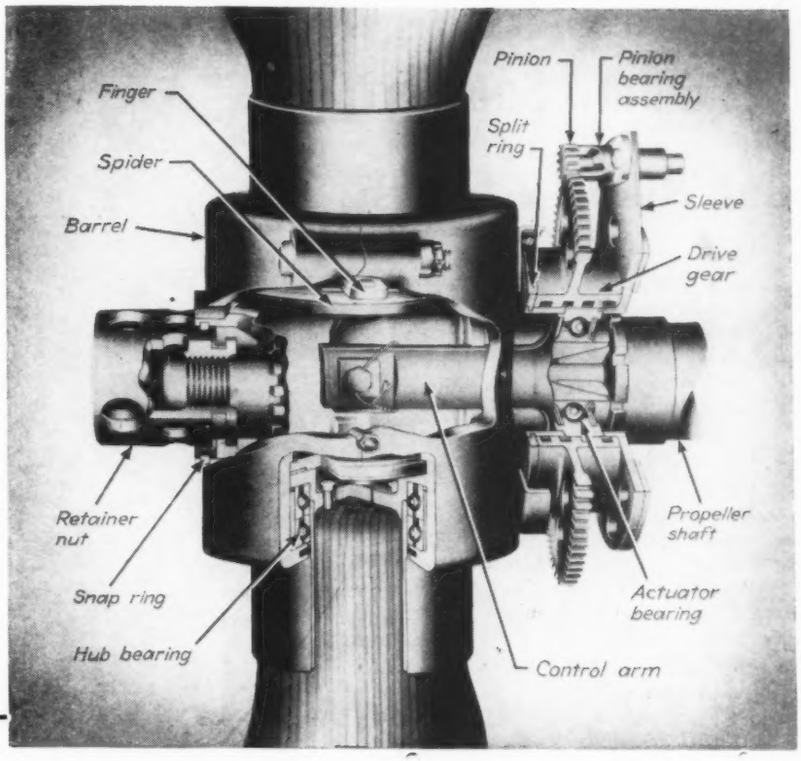


Hub assembly consists of the spider and the barrel. Central cone of spider is splined to fit engine crankshaft and each end has an accurately ground cone seat. The outer end of the spider has provisions for the retainer nut and snap ring.

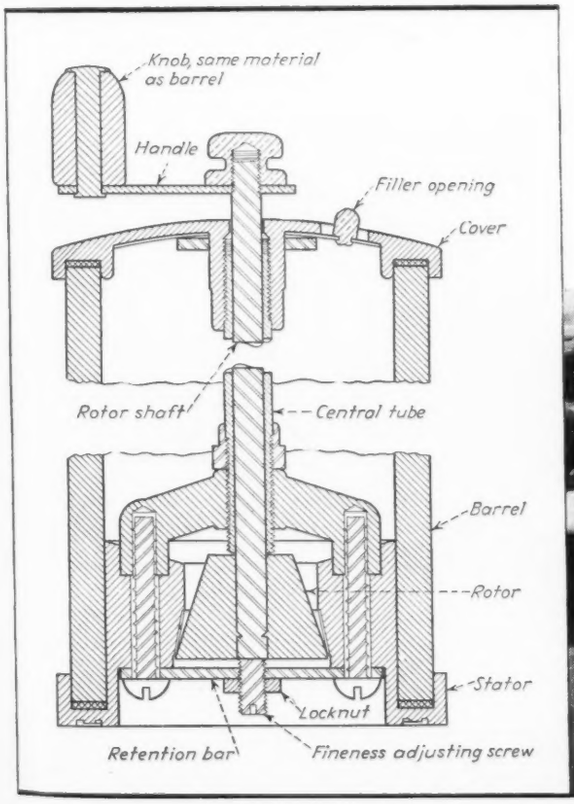


Propeller pitch is changed when electric motor rotates the pinion and gear. As gear is rotated threaded center bore drives the bearing assembly fore or aft, depending upon its direction of rotation. Control arms on the bearing assembly drive two fingers fitted in slots located in the base of the blades. Fingers are pivoted on the spider and thus rotate the blades.

Pitch control mechanism is divided into three assemblies; the actuator bearing and control arms, the pinion and gear assembly, and the drive mechanism. Actuator bearing, of the ball type, has a machined outer race, equipped with lugs, and placed inside the main drive gear and sleeve. Threads within the gear give the actuator bearing fore and aft movement. Inner race has two arms that extend into the hub. These arms join the control fingers which act as a fulcrum between the actuator bearing arms and the blades. Pinion and drive gear assembly is mounted on a sleeve bolted to the nose case of the engine. A thin split retaining ring holds the gear in place. Small pinion drives the main gear and the pinion bearing housing is attached to the sleeve by two bolts. Drive mechanism consists of an electric motor mounted on the engine, driving the pinion through a shaft and two universal joints. Electric motor operates through a worm gear drive that actuates a transmitter and opens and closes the blade angle limit switches.



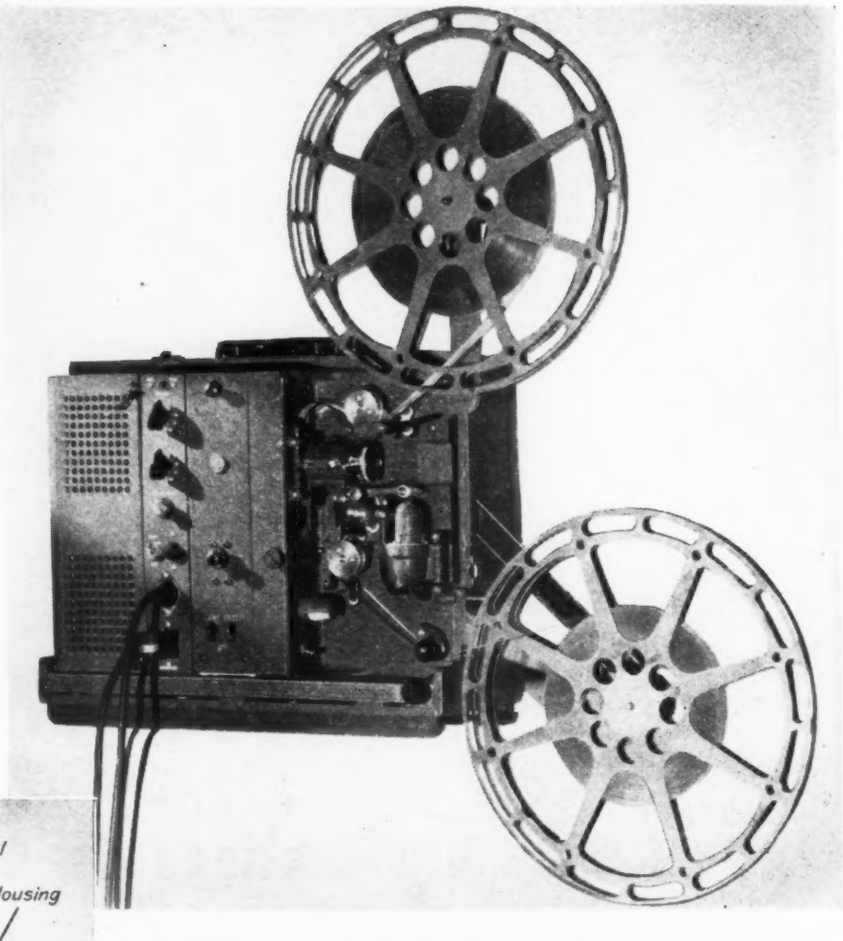
Zinc-Alloy Die Castings Used in Pepper Mill

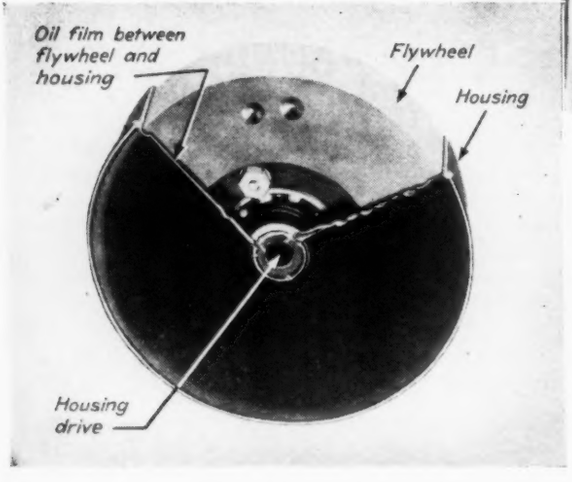


STATOR AND ROTOR of pepper mills have been redesigned by The George S. Thompson Corporation to use zinc-alloy die catings. Barrel is of plastic, wood or crystal and handle knobs match the body material. Rotor is centered by a screw located in the retention bar. Rotor can not touch stator since rotor shaft extends through a central tube whose end acts as an upper bearing for the rotor. Fineness of grind is adjusted by a headless setscrew that is held in adjustment by a locknut.

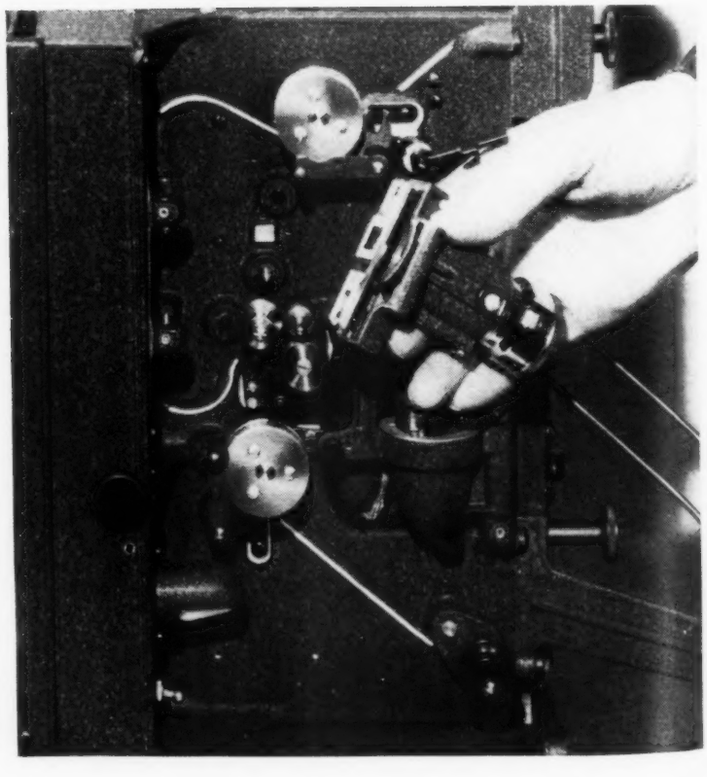
16mm. Sound Movie Projector

SOUND FILM PROJECTOR, for 16 mm. motion picture film, incorporates many wartime technical advances. Developed by the RCA Victor Division, Radio Corporation of America this projector combines professional performance with strong construction and simplicity in operation. Equipped with a 20 watt radio amplifier, the RCA sound stabilizer, a new friction-drive tension take-up and a removable film gate the machine can be threaded in the dark. Light system consists of a 750 or 1,000 watt bulb, a heat-resistant pyrex glass reflector, having a silver coating, a two element condenser and a 2 in. f:1.65 projection lens.

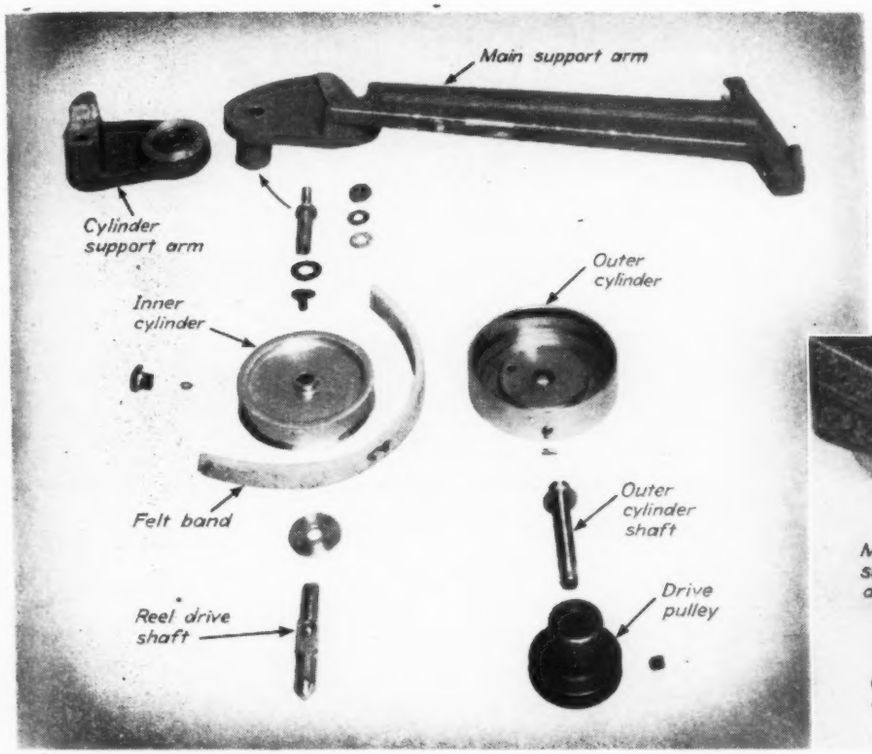




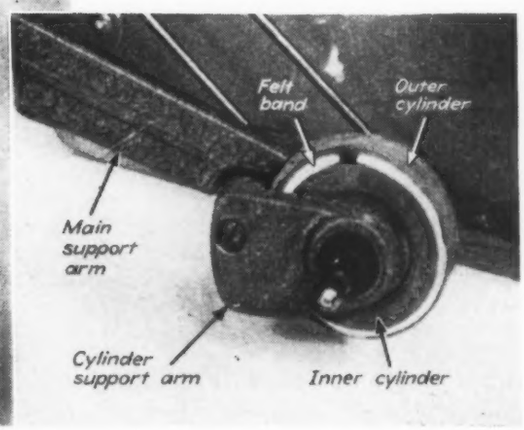
Sound stabilizer is an oil driven flywheel. The movie film rotates a small light housing that surrounds the flywheel. Oil, sealed in the housing, acts as the connecting element between the housing and flywheel. Oil film thus acts to smooth out film speed variations for sound scanning.



Film gate is removable with one hand, and is easily cleaned. Sprockets are large and operate at low speed. An embossed threading line acts as a guide for the exact length of loops and can be followed in the dark.



Take-up is belt-driven. Friction drive consists of two concentric cylinders, the outer driving the inner cylinder through friction on a layer of felt. As film winds on the take-up reel, the increasing weight results in proportionately increasing pressure on the felt. Thus, even tension is maintained automatically.



Random Notes on Reconversion

Line of food freezers has been announced by Sears Roebuck and Company. Sizes range from 6 to 18 cu. ft. and deliveries are expected to begin about the first of March.

* * *

Polythene plastic watchstraps are now being produced for sale by the Pla-Safe Plastics Corp. Straps were pre-tested by service men living under all types of climatic conditions and are guaranteed not to cause dermatitis or any irritation of the skin.

* * *

Selenium rectifier, developed by the Westinghouse Electric Corporation, will operate when submerged in boiling water or packed in ice. The rectifier consists of a heavily tin plated, hermetically sealed container inside of which the selenium is suspended in oil.

* * *

Automatic home laundry dryer announced by Bendix Home Appliances, Inc. will remove the moisture from 18 lb. of wet clothes in 45 min. Dryer can be set for damp dry or bone dry and shuts off when the desired degree of dryness has been reached. Two models, identical in appearance, will be available. Gas heated model has a 1/6 hp. 110 volt a.c. motor. Electric heated model operates on 220 volt a.c. available in homes wired for electric ranges.

* * *

American Flyer toy trains manufactured by the A. C. Gilbert Company will use a tiny electric motor developed to operate hydraulic valves of aircraft wing flaps. Engines will puff smoke and track will have only two rails. Cars will be made from plastic and weigh one-third less than a die-cast car.

* * *

Phonograph records made of Duraflex plastic are being produced by Majestic Records Incorporated. Records maintain fidelity of tone and have less surface noise and scratch than ordinary records.

* * *

Plastic-coated wire mesh window material, known as Cel-O-Glass, is again available. Used by the armed forces as a window material, it will again find use on farms in bringing the sun's ultraviolet rays indoors.

* * *

Synthetic rubber hose, reinforced with a fiber glass innerbraid, has been developed by the De Vilbiss Company for hot plastic paint at 300 deg. F. Developed for the Navy, the hose is expected to find many civilian applications.

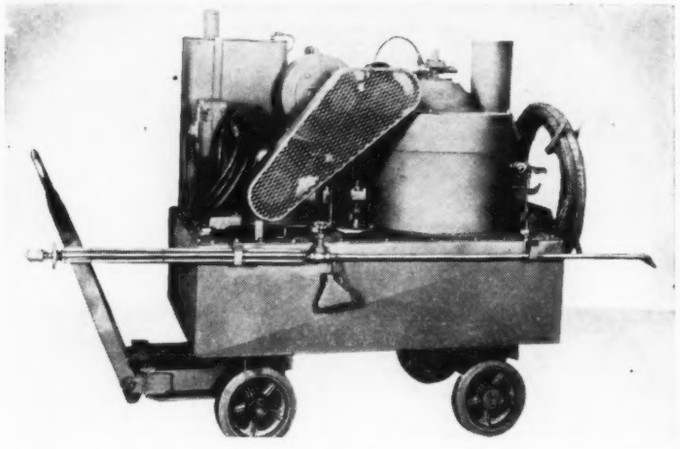
* * *

Aluminum mailboxes are being manufactured by the Ebaloy Foundries. Box is large enough for legal envelopes and bright appearance makes it more attractive than prewar models.

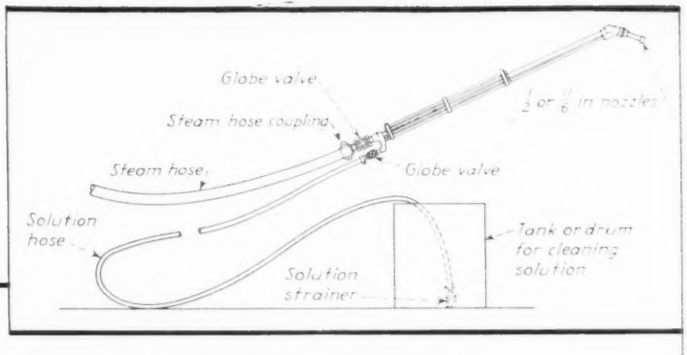
* * *

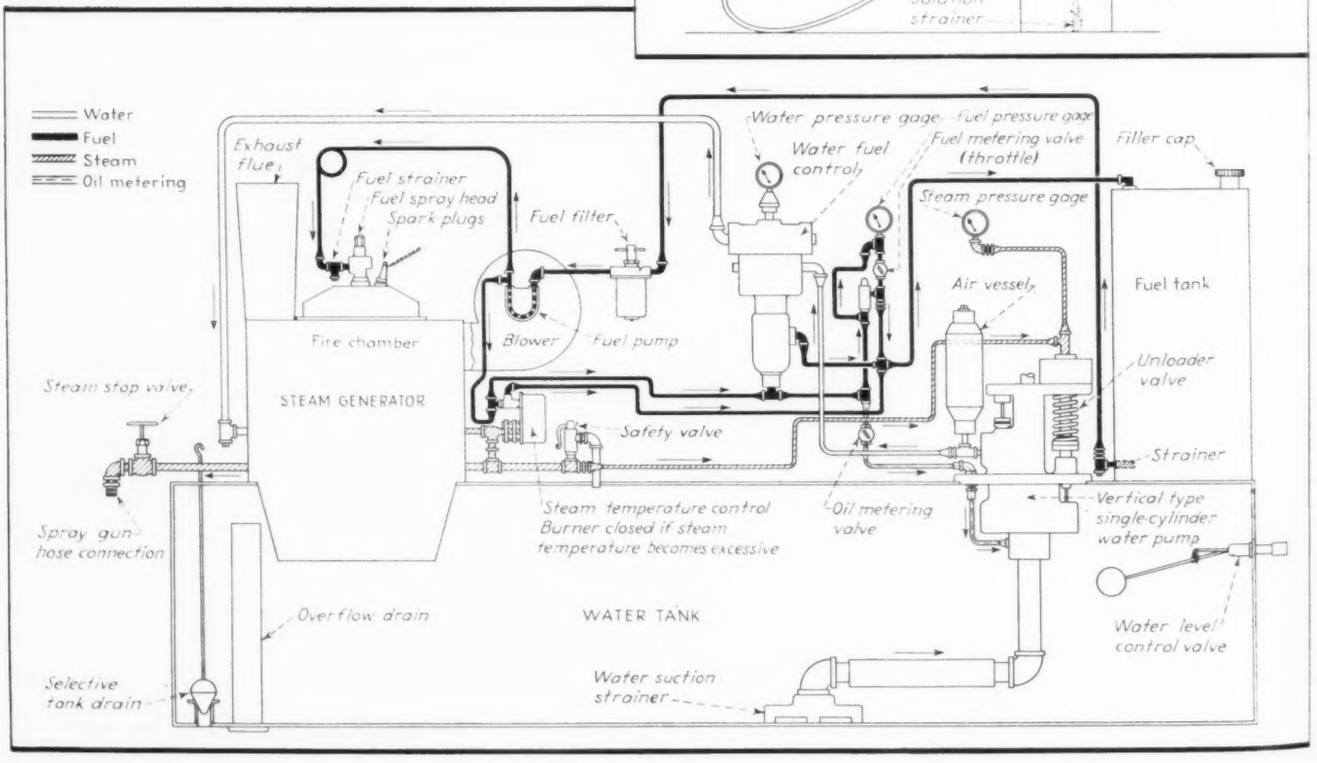
Washing machine having a "bouncing basket" has been announced by the Apex Electrical Manufacturing Company. Complete washing cycle is automatic and washes, rinses, dries and fluffs the laundry in twenty-five minutes. Basket is made of perforated aluminum and magnesium.

Self-Contained Steam Cleaning Unit



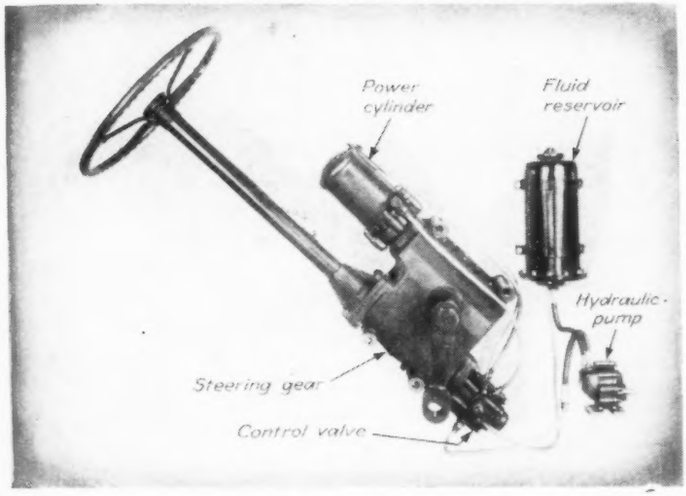
MULTIPLE-DUTY steam cleaning unit is a self-contained, down-draft flame, oil-fired, inclosed coil-type steam generator that delivers hot vaporized cleaning solutions under selective pressures up to 200 lb. per sq. in. Developed by Oakite Products, Inc. and manufactured by the Vapor Car Heating Company, the unit is known as the Oakite-Vapor cleaning unit. Designed for removal of grease, grit, grime or other surface deposits the unit is of heavy steel construction. Steam coil consists of 110 ft. of seamless steel tubing wound into four circular coil-banks in staggered positions. Power for driving all mechanical parts is obtained from a 3/4 hp. electric motor mounted on the tank. A gasoline motor can be attached to the same base as the electric motor when electric power is not available or desirable.

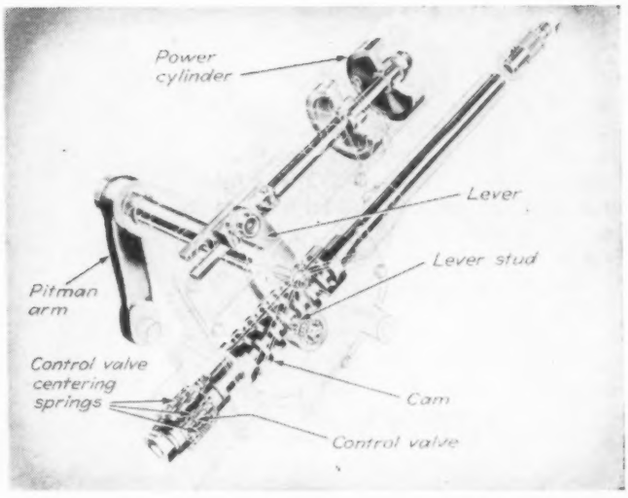




Controls are automatic and require no operational adjustments. Air vessel, mounted in the water line cushions pump pulsations. Water-fuel control automatically shuts-off fuel if water supply is exhausted or an obstruction occurs in water or fuel lines. Water pump relief valve prevents excessive pressure if water line or heating coils become clogged, vapor spray gun valve is closed and when burner is shut-down. Unloader valve limits the vapor pressure in the lines and heating coils by unloading the feed water back to the tank and shutting down the burner when a predetermined vapor pressure is reached. Oil-metering valve feeds small quantities of fuel oil to the feed water, thus reducing scale formation in the steam coil. (Insert) Cleaning solution can be circulated through the heating coils or drawn from a drum by the steam gun. The latter method minimizes coil scale and allows a plain steam rinse in the cleaning cycle which is not possible when the cleaning solution is passed through the heating coils.

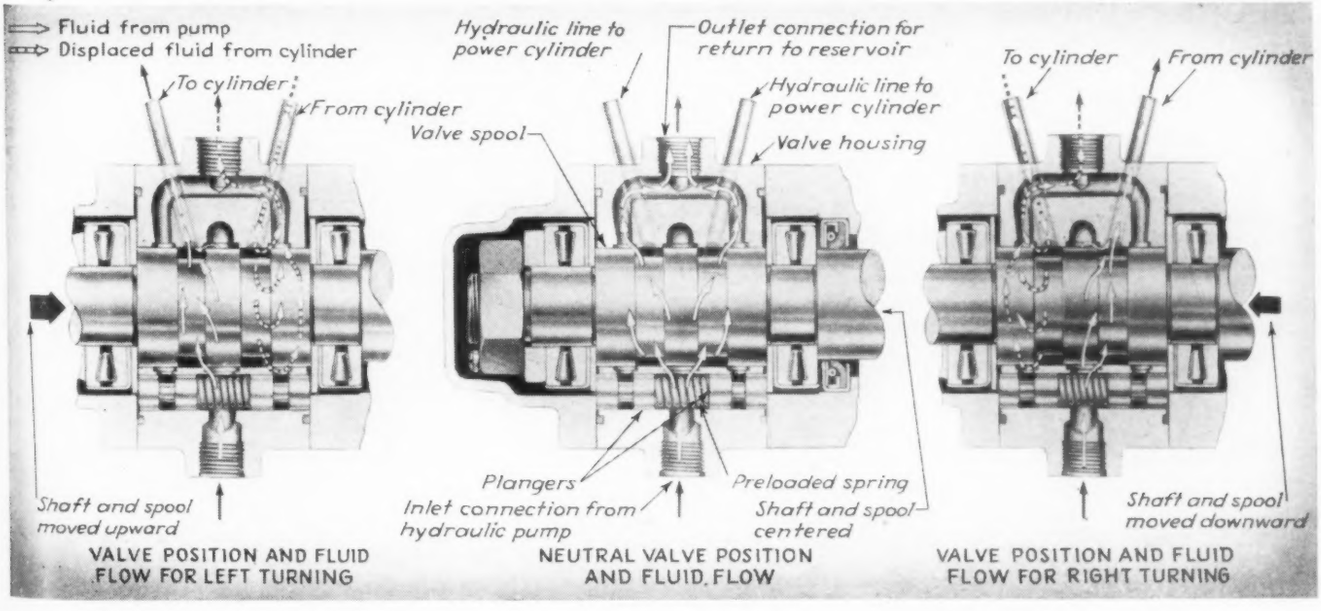
Automotive Hydraulic Steering Mechanism Assists Driver and Eliminates Road Shock





Hydraulic power steering, a device developed by the Bendix Products Division, Bendix Aviation Corporation, during the war for tank retriever service, has been converted to peacetime use in the steering of buses, trucks, well-drilling rigs and earth moving machinery. The device functions to assist normal steering so as to reduce the physical effort required of the driver. When power steering fails the vehicle still can be steered in the conventional manner. Device consists of a fluid reservoir, engine-driven hydraulic pump, steering gear, control valve and power cylinder. Hydraulic system also resists road shock thus preventing **kick-back at the steering-wheel.**

Operation of the steering wheel moves the lever stud **through the cam groove to rotate the pitman arm.** Whenever the effort at the steering wheel exceeds the preload of the control-valve centering springs, the hydraulic system comes into operation, by shifting the control valve and allowing hydraulic pressure to act on the power cylinder. Power cylinder applies hydraulic pressure directly to the lever of the steering gear.

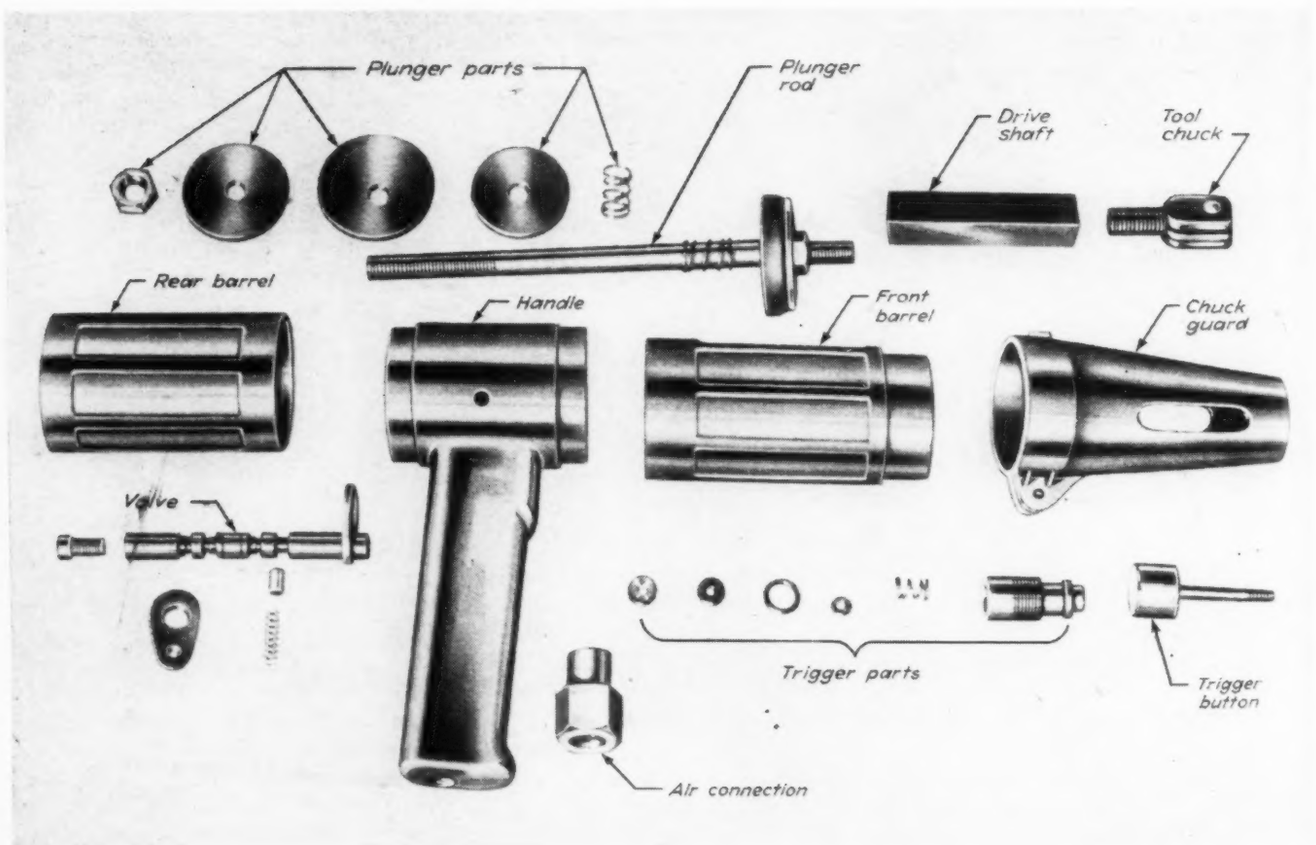

Fluid from pump
Displaced fluid from cylinder
To cylinder
From cylinder
Valve spool
Hydraulic line to power cylinder
Outlet connection for return to reservoir
Hydraulic line to power cylinder
Valve housing
To cylinder
From cylinder
Shaft and spool moved upward
Plungers
Inlet connection from hydraulic pump
Preloaded spring
Shaft and spool centered
Shaft and spool moved downward
VALVE POSITION AND FLUID FLOW FOR LEFT TURNING
NEUTRAL VALVE POSITION AND FLUID FLOW
VALVE POSITION AND FLUID FLOW FOR RIGHT TURNING

Heart of the hydraulic system is the control valve. Spool moves axially with the steering gear shaft and is restrained from movement by preloaded springs and oil acting against the plungers. Both effects tend to center the spool and hold the valve in the neutral position. In neutral position there is a balance of pressure in the power cylinder. When steering effort exerts sufficient axial thrust to overcome the preloaded springs the spool moves axially and the oil flow is directed to the power cylinder. This creates an unbalanced pressure in the power cylinder that assists the driver.

Pneumatic Sawing and Filing Tool Is Simple and Compact Design

DRIVEN BY COMPRESSED AIR and designed to simplify and speed-up sawing and filing operations in awkward or cramped quarters, this new tool is manufactured by Air-Speed Tool Company. Weighing 3 1/2 lb. the tool has an adjustable stroke of 1/4 in. to 1 1/4 in. Front barrel is adjustable and can be turned through 360 deg. thus, permitting the use of the tool in any position. Operating speeds, which depend upon trigger-valve opening, can be varied between zero and 2,500 strokes per min. Air pressure of 85 to 100 lb. per sq. in. must be maintained at the tool. Any standard type of hacksaw blade can be used and files of any shape only require that the shank be cut to 3/4 in. and ground down to 1/4 in. so that it will fit into the 1/4 in. round opening in the chuck.

Design is of simple construction. Tool has few parts and can be easily disassembled for repairs or replacement of parts.



Poor Recognition Breeds Frustration

EXECUTIVES report a pronounced drift of trained men from engineering design to other fields. Design engineers returning from the services refuse their former jobs and go into farming, selling or other callings. Many reasons are given. Pay does not seem to be the main one. The spirit of unrest created by the war, the new viewpoints gained by the individual in his war experiences, the opportunity to seek new fields, and many other stimulants have a bearing. The important questions that concern management are: How great is the movement? If it is seriously great, how can it be diminished?

Regardless of the magnitude the present drift away from design engineering, it is obviously serious. At a time when there is a 17,000 deficit of trained engineers, it seems strange that so many should forsake the profession to go into new fields in which they have had no substantial prior experience. The migration is certainly not taking place because of the dearth of engineering jobs. Nor is pay the main reason for the migration, although in companies where the salaries in the engineering department have increased in about the same ratio as wage rates, the turnover in the engineering department is not so pronounced.

Some engineering executives have expressed the opinion that the motivating force that impels designers to seek new fields stems from a lack of a sense of security. However, in view of the Social Security system and the adoption of pension plans by so many industrial companies, it doesn't seem logical that the feeling of a lack of security should now be the dominating cause for designers going into other vocations. Indeed, the engineering profession offers far greater security than many of the fields into which these men are going.

No man will change his vocation if he finds his work intensely interesting and he is paid a reasonable salary. Indeed, college professors find their work so extremely interesting that they stick to their positions in spite of miserable salaries. Because their work is so fascinating, scientists and research workers will often sacrifice higher salaries and greater leisure that they might gain by going into other fields. They may decide to take a position with another company in order to get a lucrative advancement, but they do not desert their profession.

One possible reason for the increasing exodus of men from the engineering profession is the spirit of frustration created by the lack of recognition. Medals, awards, prizes and bonuses are handed out by companies much more frequently to their commercial employees who are lauded for the success of their sales campaigns. Bonuses for sales in excess of the "bogey" are common but the engineer who made the product easy to sell is completely ignored. Frequently the designer finds himself in a bitter struggle with the commercial side of management in attempting to get recognition for the economic merit of a design. There have been too many instances wherein by duress, management at the behest of sales compelled the engineer to attempt the impossible and then blamed him because the product failed.

Young engineers are quick to sense what is going on. Some of them finally conclude that Preston, the great English scientist was right when he wrote, "Charlatans and quacks flourish, while the spirit of true science sickens in the struggle." So the young designer decides there is no sense in getting sick, and therefore gives up the struggle and starts anew in some other field that seems more congenial.

Employee morale must be developed by convincing the man that his position is one that carries with it not only prestige, but also respect for his personal dignity. His position in the councils of the company and his pay must bespeak a high evaluation of his opinions, work and accomplishment. Thus will be built in the heart and mind of the individual, a conviction that design engineering is an enviable profession.

There will always be a drift away from the engineering design profession, a natural sifting out of the misfits and the incompetent. But when qualified capable trained engineers throw away their life-time investment in education and experience to seek what seems to them a better life in strange fields, it is up to management to do something about it.

G. F. Nordenholt.

MECHANICAL DEVICES FOR

Speed governors, designed to maintain speeds of machines within reasonably constant limits irrespective of loads, may depend for their action upon centrifugal force or cam linkages. Other types may utilize pressure differentials and fluid velocities as their actuating media. Examples of these governing devices are illustrated.

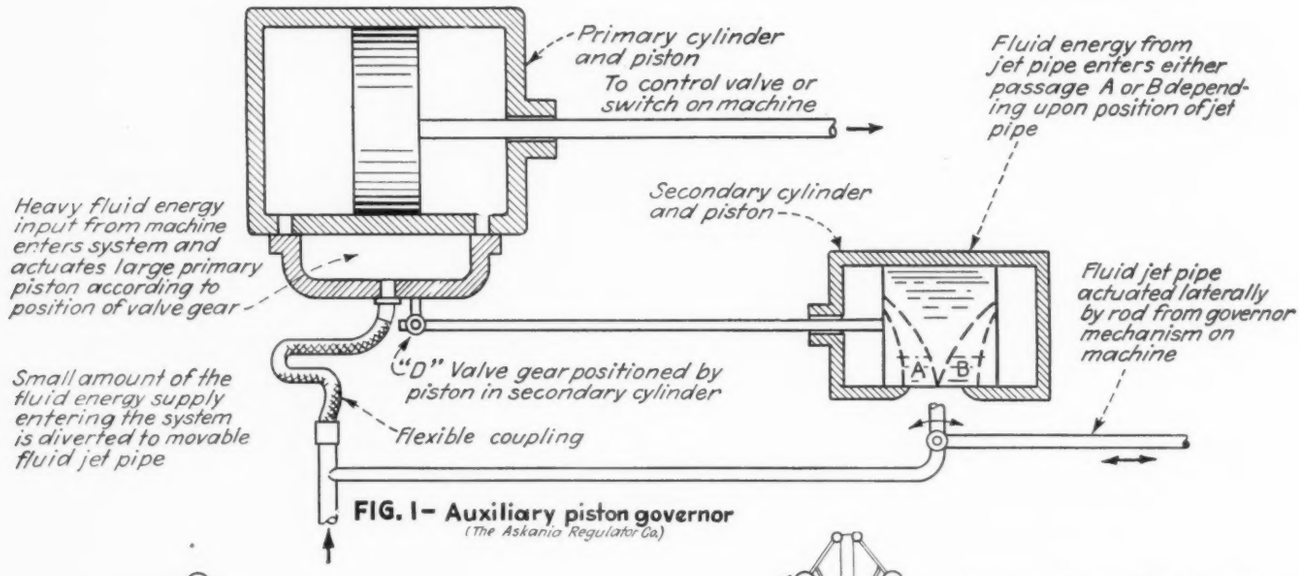

Primary cylinder and piston
To control valve or switch on machine
Fluid energy from jet pipe enters either passage A or B depending upon position of jet pipe
Secondary cylinder and piston
Heavy fluid energy input from machine enters system and actuates large primary piston according to position of valve gear
Fluid jet pipe actuated laterally by rod from governor mechanism on machine
"D" Valve gear positioned by piston in secondary cylinder
A
V
B
Small amount of the fluid energy supply entering the system is diverted to movable fluid jet pipe
Flexible coupling

FIG. 1– Auxiliary piston governor
(The Askania Regulator Co.)

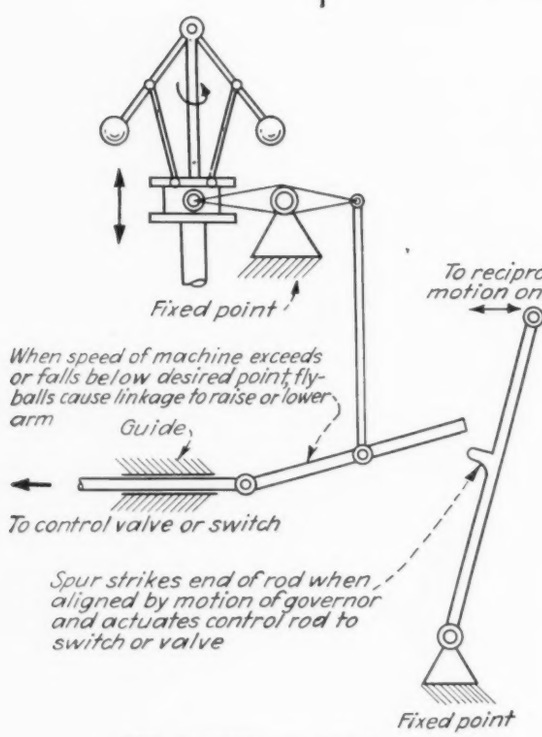

Fixed point
When speed of machine exceeds or falls below desired point, flyballs cause linkage to raise or lower arm
Guide
To control valve or switch
Spur strikes end of rod when aligned by motion of governor and actuates control rod to switch or valve
Fixed point

FIG. 2– Hit-and-miss governor

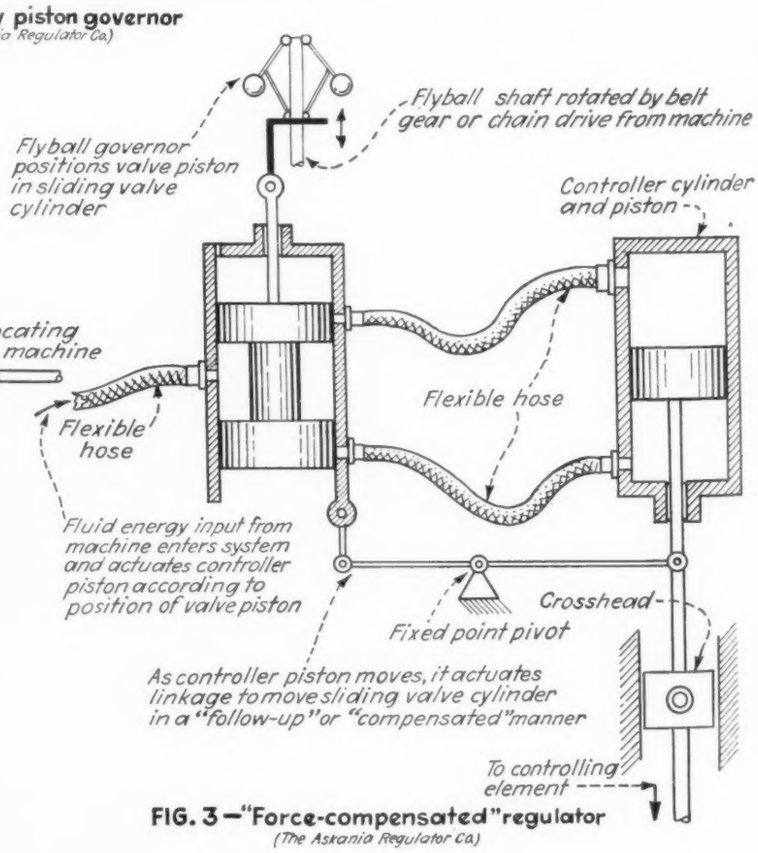

Flyball shaft rotated by belt gear or chain drive from machine
Flyball governor positions valve piston in sliding valve cylinder
Controller cylinder and piston
To reciprocating motion on machine
Flexible hose
Flexible hose
Fluid energy input from machine enters system and actuates controller piston according to position of valve piston
Crosshead
Fixed point pivot
As controller piston moves, it actuates linkage to move sliding valve cylinder in a "follow-up" or "compensated" manner
To controlling element

FIG. 3–"Force-compensated" regulator
(The Askania Regulator Co.)

AUTOMATICALLY GOVERNING SPEED

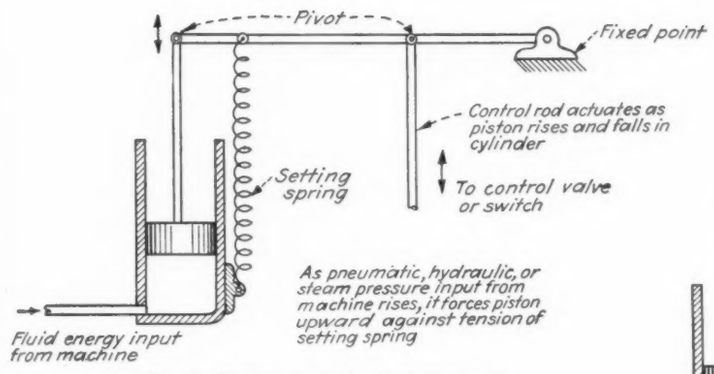

Pivot
Fixed point
Control rod actuates as piston rises and falls in cylinder
Setting spring
To control valve or switch
As pneumatic, hydraulic, or steam pressure input from machine rises, it forces piston upward against tension of setting spring
Fluid energy input from machine

FIG. 4– Pressure-actuated governor

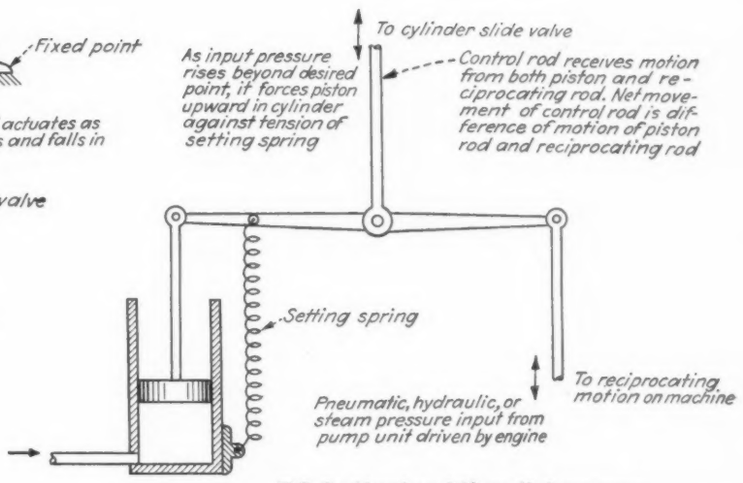

To cylinder slide valve
As input pressure rises beyond desired point, it forces piston upward in cylinder against tension of setting spring
Control rod receives motion from both piston and reciprocating rod. Net movement of control rod is difference of motion of piston rod and reciprocating rod
Setting spring
To reciprocating motion on machine
Pneumatic, hydraulic, or steam pressure input from pump unit driven by engine

FIG. 5– Varying differential governor

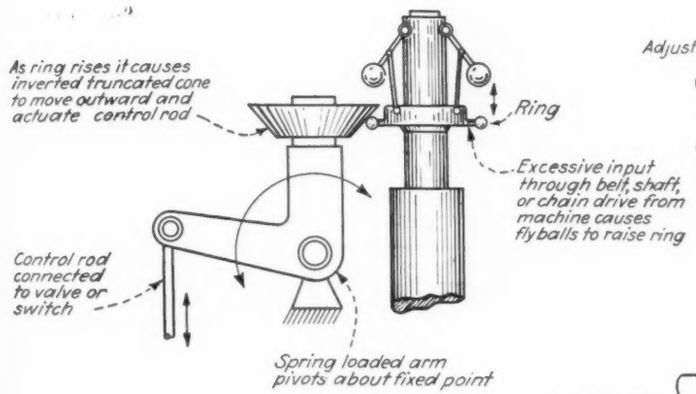

As ring rises it causes inverted truncated cone to move outward and actuate control rod
Ring
Excessive input through belt, shaft, or chain drive from machine causes flyballs to raise ring
Control rod connected to valve or switch
Spring loaded arm pivots about fixed point

FIG. 6– Centrifugal governor

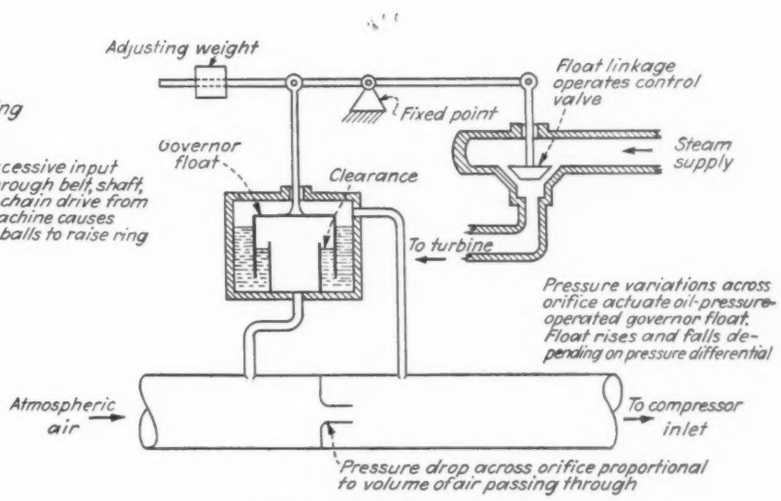

Adjusting weight
Float linkage operates control valve
Fixed point
Governor float
Clearance
Steam supply
To turbine
Pressure variations across orifice actuate oil-pressure-operated governor float. Float rises and falls depending on pressure differential
Atmospheric air
To compressor inlet
Pressure drop across orifice proportional to volume of air passing through

FIG. 7– Constant volume governor

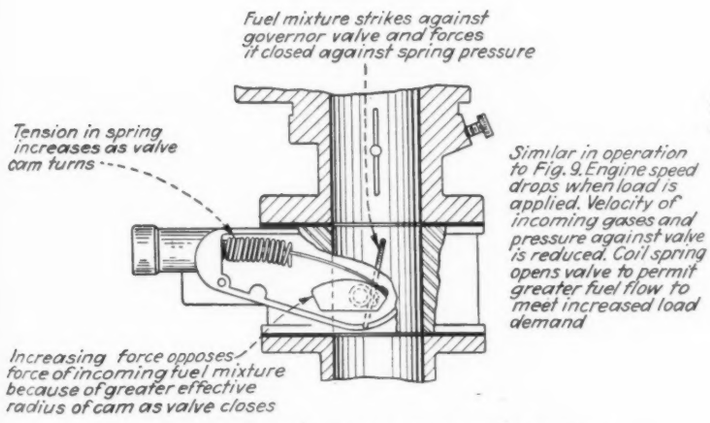

Fuel mixture strikes against governor valve and forces it closed against spring pressure
Tension in spring increases as valve cam turns
Similar in operation to Fig. 9. Engine speed drops when load is applied. Velocity of incoming gases and pressure against valve is reduced. Coil spring opens valve to permit greater fuel flow to meet increased load demand
Increasing force opposes force of incoming fuel mixture because of greater effective radius of cam as valve closes

FIG. 8– Velocity-type governor (coil spring)

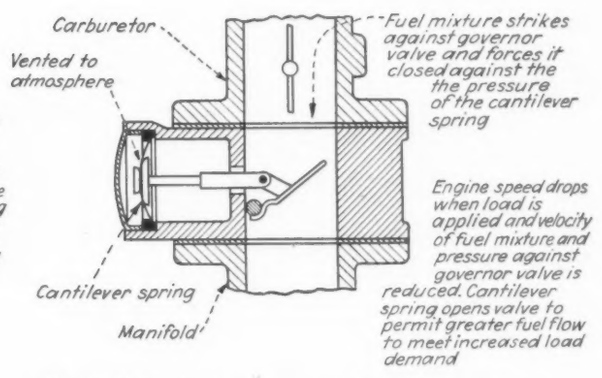

Carburetor
Vented to atmosphere
Fuel mixture strikes against governor valve and forces it closed against the the pressure of the cantilever spring
Engine speed drops when load is applied and velocity of fuel mixture and pressure against governor valve is reduced. Cantilever spring opens valve to permit greater fuel flow to meet increased load demand
Cantilever spring
Manifold

FIG. 9– Velocity-type governor (cantilever spring)

Leakage in Capillary Seals Of Hydraulic Valves and Pumps

PAUL G. EXLINE
Research Engineer, Gulf Research & Development Company

Formulas for calculating the volume of leakage of viscous fluids through concentric and eccentric radial clearance spaces. Effects of the rate of doing work in shearing the oil film, changes of temperature and pressure on the viscosity of mineral oils are evaluated. Dimensional changes by temperature rise and pressure are discussed.

CAPILLARY SEALS are used to reduce leakage past members entering a hydraulic system and to obtain a minimum of frictional resistance to motion of the member. A common form is a cylindrical rod passing through a clearance hole in a pressure vessel, the leakage taking place through the annular space between the rod and the hole. The equations given in this discussion were developed to make available a reference source for use in flow problems. In analyzing each problem it is assumed that the capillary seals are of such small dimensions that flow velocities cannot reach a value high enough to cause turbulence.

Where Q = volume rate of flow
P = total pressure drop
L = length of flow path
r = radius of inner cylinder
R = radius of outer cylinder
μ = viscosity of the fluid

The equation of viscous flow through the annular space between two concentric cylinders is given by Lamb as

$$Q = \frac{\pi P}{8\mu L}\left[(R^4 - r^4) - \frac{(R^2 - r^2)^2}{\log_e (R/r)}\right] \quad (1)$$

When the values of r and R differ by a small amount, as in a lapped fit, use of Equation (1) is quite difficult as the numerical values must be carried out 12 to 15 significant figures for accurate results. But where h is the radial clearance by letting

$$R = r + h$$

Equation (1) can be reduced to

$$Q = \frac{\pi}{6}\frac{rh}{\mu L}P\left(1 + \frac{1}{2}\frac{h}{r} + \frac{1}{60}\frac{h^2}{r^2} - \frac{1}{120}\frac{h^3}{r^3}\cdots\right) \quad (2)$$

In capillary seals, the ratio of h/r is rarely greater than 0.001, so that all terms in the parentheses containing this ratio can be neglected, thus reducing Equation (2) to

$$Q = \frac{\pi}{6}\frac{rh^3 P}{\mu L} \quad (3)$$

This equation could also be derived from that for flow between flat parallel plates separated a distance h, where w is the width of the flow path,

$$Q = \frac{wh^3 P}{12\mu L} \quad (4)$$

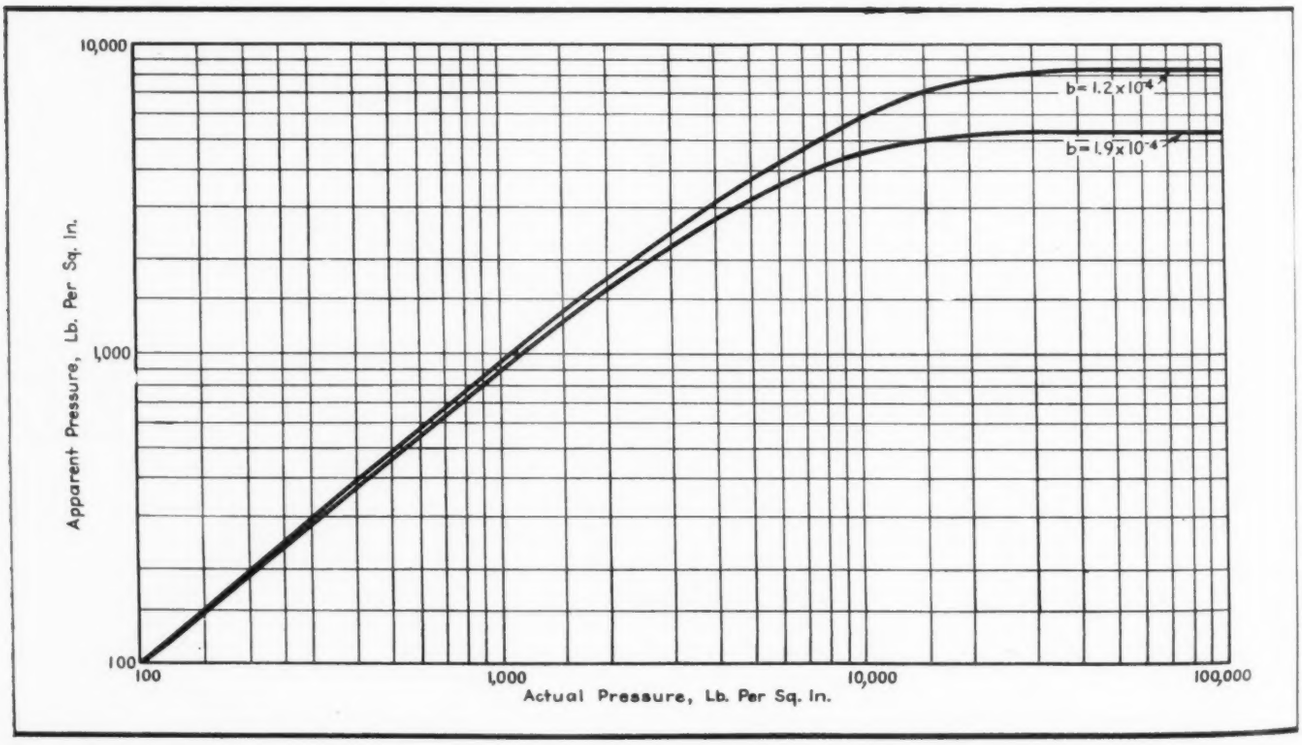


Fig. 1—Apparent pressure plotted as a function of actual pressure for two pressure coefficients of viscosity.

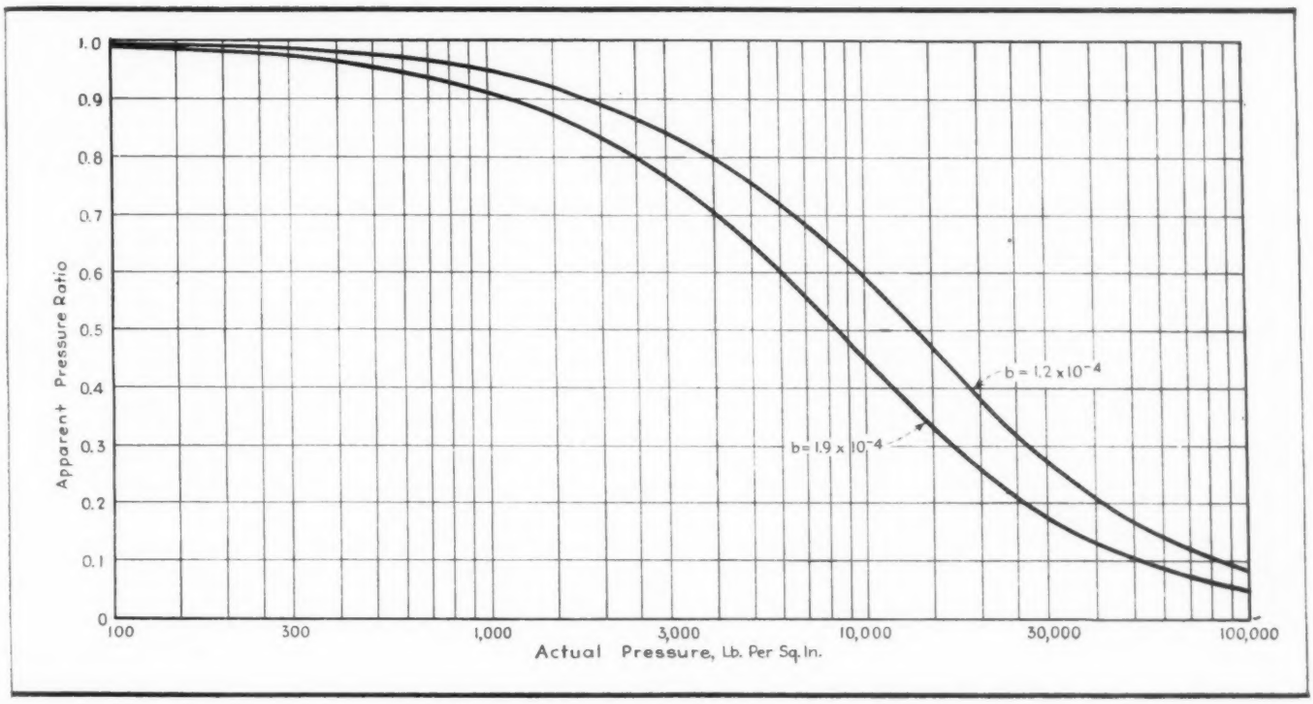


Fig. 2—Ratio of apparent pressure to actual pressure plotted as a function of actual pressure for two pressure coefficients of viscosity. Curves show reduction in flow of viscous fluids as actual pressure increases.

For concentric cylinders, the width of the path is equal to the circumference of the annulus, or

$$w = 2\pi r$$

which substituted in Equation (4) gives Equation (3).

The magnitude of the errors resulting from the curvature of the flow path when using Equation (3) can be checked by Equation (2). With h/r equal to 0.02, the error is one percent, and for all smaller values of h/r it will be less.

In calculating flow it is generally more convenient to use the diameter D of the inner cylinder or piston and the diametral clearance C between piston and cylinder.

Substituting D for $2r$ and C for $2h$ in Equation (3)

$$Q = \frac{\pi DC^3 P}{96\mu L} \qquad (5)$$

When a piston and cylinder are not concentric with a uniformly thick film separating the two, and where e is the eccentricity ratio, that is, the ratio of the distance between the centers of the piston and cylinder to the radial clearance,

$$Q = \frac{\pi DC^3 P}{96\mu L}(1 + 1.5e^2) \qquad (6)$$

When the piston and cylinder are concentric, e equals 0. When the piston is touching the cylinder on a line throughout its length, e equals 1, and the flow becomes 2.5 times that for the concentric position.

With lapped fits it is practically impossible to determine the eccentricity experimentally. Equations (5) and (6) set limits for the flow that cannot be passed. In a piston rotating with little radial load, the eccentricity is negligibly small even at low speeds.

Table I—Atmospheric Viscosities and Pressure Coefficients of Four Oils

Oil	μ_0, centipoises at		b, sq. in. per lb., at	
	100 deg. F.	180 deg. F.	100 deg. F.	180 deg. F.
GR 2544	40.49	7.07	1.734×10^{-4}	1.447×10^{-4}
GR 1277	55.73	10.60	1.527×10^{-4}	1.264×10^{-4}
GR 1634	57.03	9.39	1.851×10^{-4}	1.439×10^{-4}
GR 3117	77.94	11.75	1.898×10^{-4}	1.373×10^{-4}

In the foregoing equations it was assumed that the viscosity of the fluid remained constant throughout the flow path. This will be substantially true if there are no variations in temperature and if moderate pressures are used. When the driving pressure becomes high, as in hydraulic systems, it will be necessary to correct for the increase in viscosity caused by pressure.

The variation in viscosity with pressure, where μ_0 is the viscosity at atmospheric pressure and b is the pressure coefficient of viscosity, is generally expressed as an exponential

$$\mu = \mu_0 e^{bP} \qquad (7)$$

When a high pressure is applied to force the liquid through the seal, the pressure gradient is no longer constant throughout the length of the seal and the flow equation is altered to

$$Q = \frac{\pi DC^3}{96\mu_0 L} \cdot \frac{(1 + 1.5e^2)(1 - e^{-bP})}{b} \qquad (8)$$

From Equation (8) it can be seen that P has been replaced by the term

$$\frac{1}{b}(1 - e^{-bP})$$

At extremely high pressures the exponential e^{-bP} will become negligibly small and the entire term becomes a constant equal in value to the reciprocal of the pressure coefficient. Such pressures are beyond the range normally used in hydraulic systems, but it is of interest to note that the flow can become substantially independent of pressure. Calling this term the apparent pressure and plotting it as a function of actual pressure gives curves as shown in Fig. 1. Two values of b are used in this plot corresponding to the extremes of the values shown in Table I. When computing viscous flow through any conduit of constant section the atmospheric viscosity can be used in the appropriate equation, but the apparent pressure corresponding to the actual pressure must also be used.

More striking are the curves of Fig. 2, in which the same data have been used to

plot the ratio of apparent pressure to actual pressure against the actual pressure. This shows that at 10,000 lb. per sq. in. the flow could drop to 50 percent of its value if the oil were uninfluenced by pressure. Even at 1,000 lb. per sq. in. a reduction of 7 percent is of significance.

In this discussion it has been assumed that b is a constant throughout the pressure range. Actually, it decreases slowly with increasing pressure until the material becomes plastic or solid. Up to 5,000 lb. per sq. in. the change in b is negligibly small as demonstrated in Figs. 3 and 4. By dividing Equation (7) through by μ_o and taking the natural logarithm,

$$\log_e \frac{\mu}{\mu_o} = bp$$

The plot of the logarithm of the viscosity ratio should then be a straight line passing through the origin and having the slope b. This has been done in Fig. 3 and the pressure coefficients taken from the graph. To demonstrate how well the empirical Equation (7) fits the experimental data, pressure-viscosity values were computed using the value of b determined in this manner. The result for one oil is given in Fig. 4, the solid lines were drawn through the computed points (not shown) and the experimental results were indicated by dotted circles. It is quite evident that over this range the chosen value of b permitted accurate prediction of the viscosity.

A further comparison showed that similar calculations and experimental results for the other oils also check. Table I gives the atmospheric vicosities and pressure coefficients of the four oils. (An execellent summary of other work on pressure-viscosity relationships has been prepared by M. D. Hersey and R. F. Hopkins, "Viscosity of Lubricants Under High Pressure", *Mechanical Engineering*, December 1945, p. 820.)

It might be expected that a further correction should be made to the flow equation to account for the compressibility of the oil. R. B. Dow and C. E. Fink (see "Some Properties of Lubricating Oils at High Pressure-Density," *Journal of Applied Physics* 11, p. 353, May, 1940 have shown that if

p = pressure, lb. per sq. in.
ρ = density in grams per cc. at pressure p and temperature t deg. F.
ρ_0 = density at atmospheric pressure and temperature t

A and B are parameters the magnitudes of which are functions of temperature

$$\rho = \rho_0 (1 + Ap - Bp^2)_t \qquad (10)$$

Compressibility K of an oil is defined as

$$\frac{-1}{v} \frac{dv}{dp}$$

which is also equal to

$$\frac{1}{\rho} \frac{d\rho}{dp}$$

Differentiating Equation (10) and making

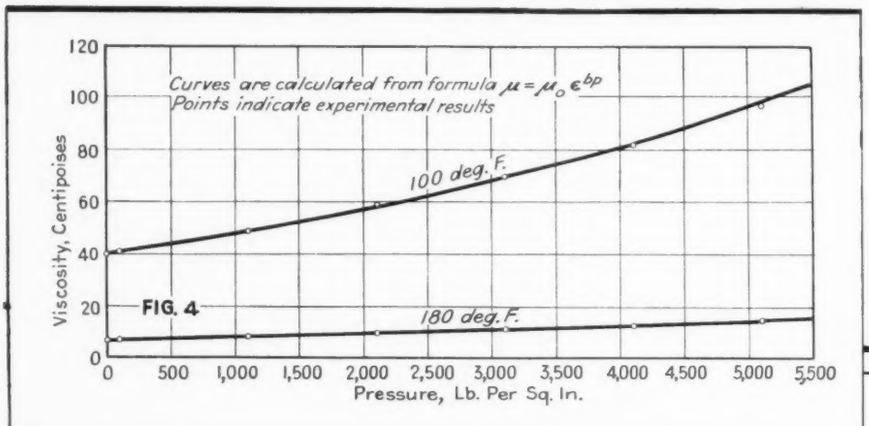
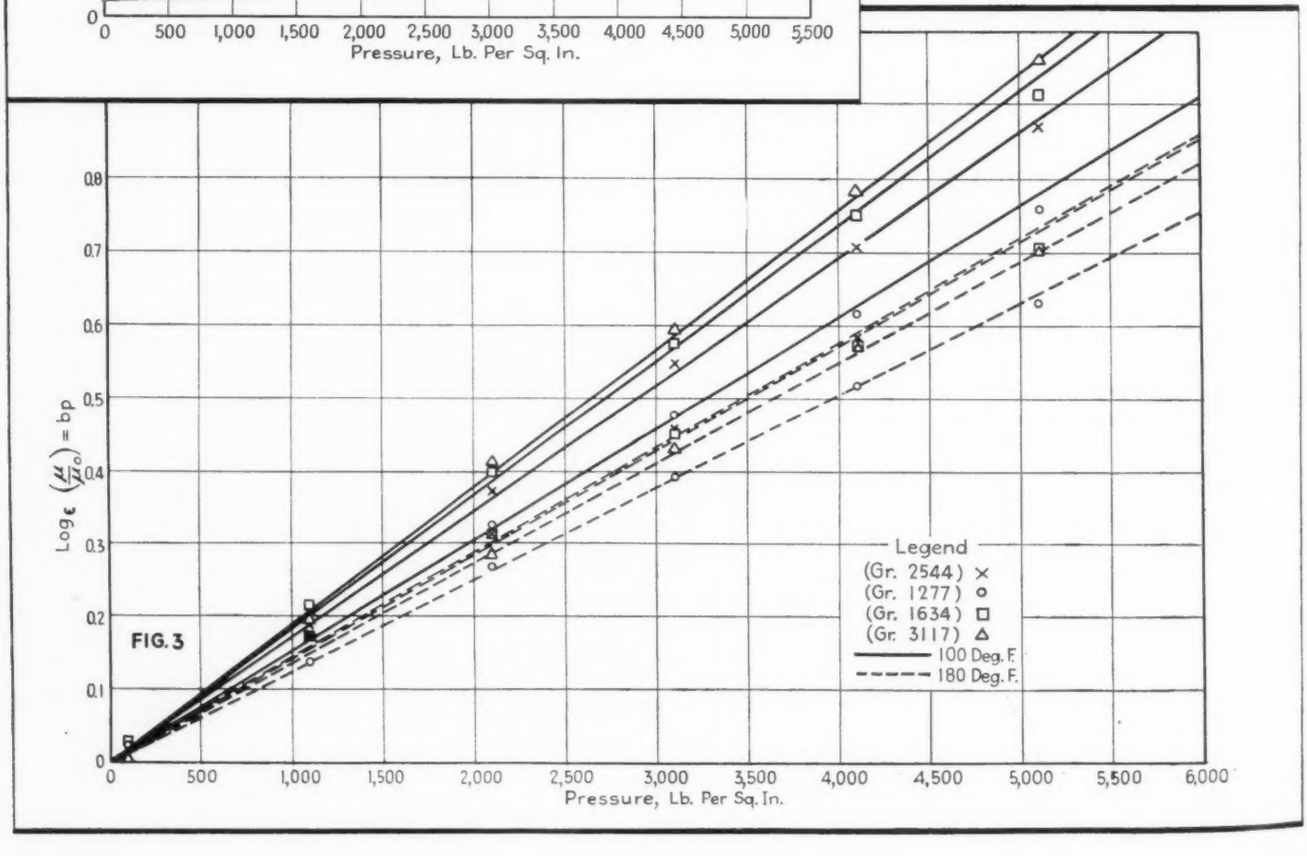
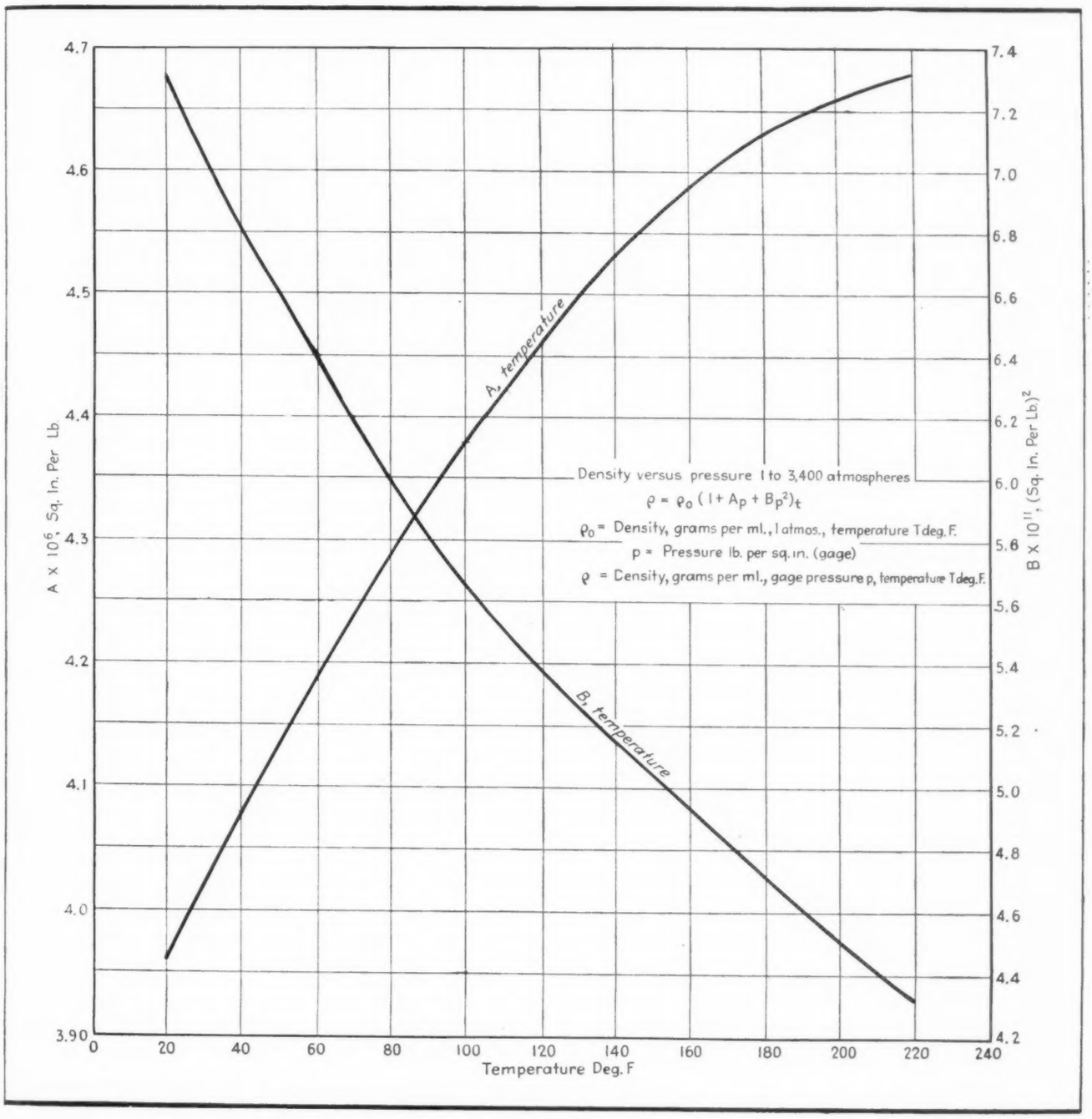


Fig. 3—Relation between the natural logarithm of the ratio of viscosity at a given pressure to the viscosity at atmospheric pressure and the given pressure of four different oils.

Fig. 4—Relation between viscosity and pressure for GR 2544 oil as calculated and checked with experimental results.





Journal of Applied Physics

Fig. 5—Constants for calculating the relation between dens ity and pressure of lubricating oils at different temperatures.

the necessary substitutions gives the equation

$$K = \left(\frac{A - 2Bp}{1 + Ap - Bp^2}\right)_t \qquad (11)$$

Values of A and B are given in Fig. 5, which is taken from the paper by Dow and Fink. Application of the values at 100 deg. F. show that the total compression of an oil is only 3 percent at 10,000 lb. per. sq. in. For this reason it is considered unnecessary to develop an equation to correct for the con.pressibility.

The effect of temperature on the viscosity of a mineral oil is generally recognized and is much more pronounced than the pressure effect. Various empirical equations have been proposed for expressing the relationship, but the most convenient way of finding viscosities at different temperatures is to use the A.S.T.M. Viscosity Temperature Chart D 341-43.

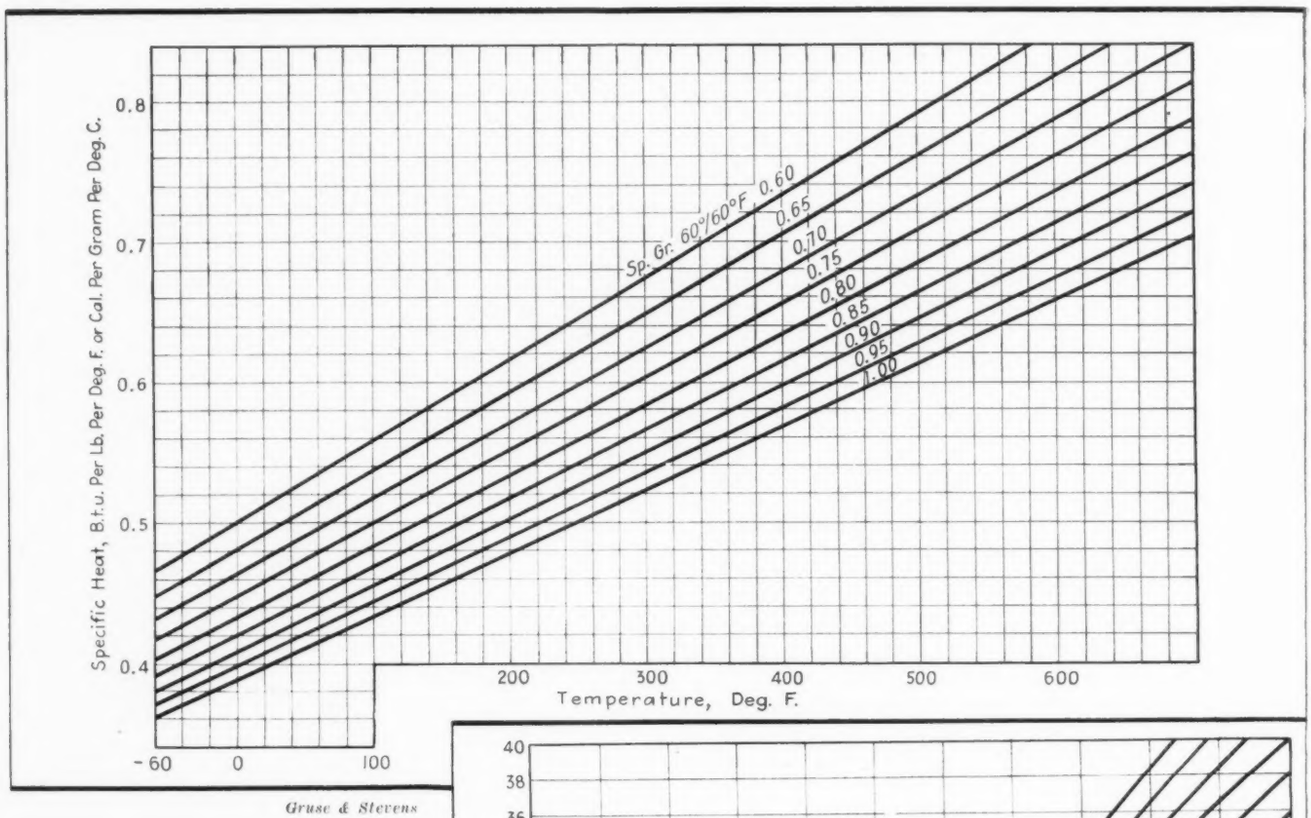
On this chart the kinematic viscosity-temperature relationship is represented by a straight line drawn through two points determined experimentally.

For analytical work the equation,

$$\mu = at^{-k} \qquad (12)$$

t represents the Fahrenheit temperature, k the temperature coefficient of viscosity, and a an empirical constant, is useful. When the values of the constants are determined from the results of viscosity measurements at 100 and 210 deg. F., Equation (12) can safely be used for temperatures from 100 to 300 deg. F. At temperatures below 100 deg. F., the calculated curve will deviate rather badly from the true curve, therefore, the constants should be determined from measurements bracketing the range in which the equation is to be used.

Heat will be generated in the liquid by the work done in forcing it through the



Gruse & Stevens

Fig. 6—Specific heat of hydrocarbon liquids of different specific gravities at different temperatures.

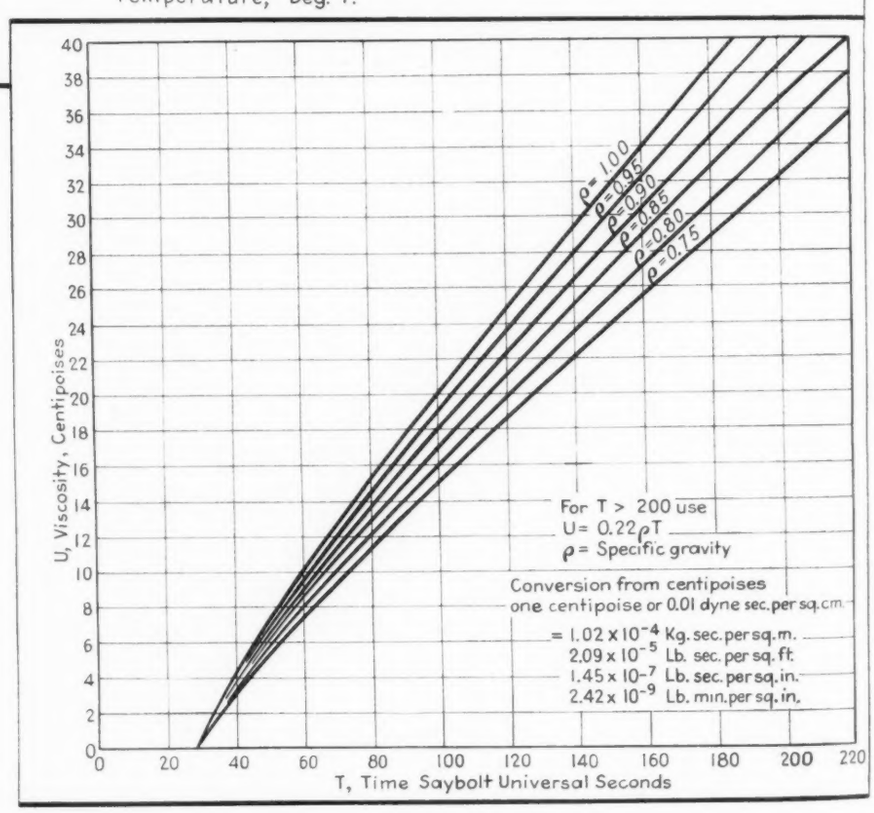


Fig. 7—Chart for converting Saybolt Universal Seconds to units of absolute viscosity in centipoises.

seal. The resulting temperature rise in the oil can readily be computed if it be assumed that all the heat remains in the oil and none is carried off through the apparatus by conduction. With

Δt = temperature rise, deg. F.
P = pressure, lb. per sq. in.
s = specific heat of oil, B.t.u. per lb. per deg. F.
ρ = density of oil, lb. per cu. in.
m = mechanical equivalent of heat, in. lb. per B.t.u.

$$\Delta t = P/ms\rho \qquad (13)$$

Using units of pounds, inches, and minutes

$m = 9.35 \times 10^3$ in. lb. per B.t.u.
ρ = approx. 0.0296 lb. per cu. in. for mineral oils
s = approx. 0.5 B.t.u. per lb. per deg. F.
Δt = 7 deg. F. per 1,000 lb. per sq. in.

In Table II, conversion factors for fluid density are given for oils that range from 0.75 to 1.00 specific gravity. The chart in Fig. 6 gives specific heats of hydrocarbon liquids that range from 0.60 to 1.00 specific gravity.

In practice the temperature rise of the oil will be less than the value given because of heat loss through the cylinder wall by conduction and from the cylinder either by radiation, convection or conduction. Accurate prediction of the temperature rise requires consideration of all these factors. The actual generation of heat H is relatively small since

$$H = PQ \qquad (14)$$

For a pressure of 3,000 lb. per sq. in. and a leakage rate of 3 cu. in. per min., H is 9,000 in. lb. per min. or 17 watts.

Additional heat will also be generated when there is relative motion between the two cylinders such as reciprocation or rotation of one member in another.

When one cylinder is rotating within the other, and

μ = kinematic viscosity, centipoises
L = length of shearing surface, in.
D = dia. of shearing surface, in.
N = rotational speed, r.p.m.

the rate of doing work in shearing the oil film is

$$H_s = \frac{2\pi^3 \mu L N^2 D^3}{C} \qquad (15)$$

Additional work is done by the axial flow of the liquid as given in Equation (14). If all the heat is retained in the oil, the temperature rise of the oil will be

$$\Delta t = \frac{192\pi^2 \mu^2 D^2 N^2 L^2}{C^4 P \rho s m} + \frac{P}{\rho s m} \qquad (16)$$

From Equation (16) it can be seen that the magnitude of the contribution of the rotational work to the temperature rise will depend upon the pressure. At low pressures the temperature rise will result largely from the work of rotating the shaft, while at high pressures the hydraulic loss will become predominant.

In practice it is impossible to retain all the heat in the oil since shafts and sleeves are good conducting mediums for carrying away heat. If the heat loss is proportional to the elevation of the average temperature of the oil film above ambient temperature, and

t_o = oil inlet temperature
t_a = ambient temperature
J = heat transfer coefficient of cylinder and piston assembly

the temperature rise would be

$$\Delta t = \frac{(2\pi^2 \mu L N^2 D^3 / C) + PQ - m(t_o - t_a) J}{Q \rho s m + (mJ/2)} \qquad (17)$$

Where the inner cylinder is moving longitudinally with a constant velocity v, the rate of doing work is

$$H = 2\pi \mu z^2 D L / C \qquad (18)$$

and temperature rises can be found as before.

The only significant application likely to arise in aviation hydraulic equipment is that of the rotating shaft on a hydraulic pump or motor. So far as the author is aware, there is no design based upon a rapid reciprocation of pistons in a cylinder at a point of emergence from the housing where a capillary seal might be used. All the other reciprocating mechanisms are those of operating valves, or relatively slow moving devices, in which no appreciable heat would develop from the movement of the parts.

In design calculations, Equations (14) to (18) are useful in estimating the maximum possible temperature rise, but they can be applied only when the temperature rises are quite small and even then are somewhat in error because of the assumption that the viscosity in the flow path is not altered by the temperature rise.

Somewhat better accuracy can be obtained by using the average viscosity over the flow path in the foregoing equations. Thus with

t_o = oil inlet temperature
$t_o + \Delta t$ = oil final temperature
μ_1 = kinematic viscosity of oil at inlet
μ_2 = kinematic viscosity of oil at outlet

the average viscosity μ_m is obtained from

$$\mu_m = \frac{\mu_1 + \mu_2}{2} = \frac{\mu_1}{2}\left(1 + \frac{\mu_2}{\mu_1}\right) \qquad (19)$$

From Equation (12)

$\mu_1 = a\, t_o^{-k}$
$\mu_2 = a\,(t_o + \Delta t)^{-k}$

substituting these values in Equation (19)

$$\mu_m = \frac{\mu_1}{2}\left[1 + \left(\frac{t_o}{t_o + \Delta t}\right)^k\right] \qquad (20)$$

The value of μ_m from Equation (20) can be substituted for μ in Equations (16) and (17), and the value of Δt determined.

In the foregoing discussion, little has been said about units. All the equations can be used with any system of units provided they are consistent. This author prefers the pound force, minute, inch system as being more consistent with engineering practice dealing with small equipment. Dimensions are generally given in inches, weights in pounds, rotative speeds in revolutions per minute, and small flows in cubic inches per minute.

In such a system the manner of handling the viscosity can be troublesome. Viscosities are most frequently reported in Saybolt Universal Seconds, while kinematic viscosity or centistokes and absolute viscosity or centipoises are less often used. Before Saybolt Universal Seconds can be used in any equation they must be converted either to kinematic or absolute viscosity, preferably the latter. With the chart given in Fig. 7 Saybolt seconds can be readily converted to absolute viscosity in centipoises. To convert centipoises to pound minute per square inch units, multiply by 2.42×10^{-9}. Kinematic viscosity is absolute viscosity divided by the density of the liquid. If viscosities are reported in centistokes, they can be converted to centipoises by multiplying by the density.

Radial flow of liquid between parallel annular plates may occasionally be encountered. When the outside diameter of the plates is D_p the inside diameter d_p and the separation C the flow will be

$$Q = \frac{\pi C^3 P}{6\mu \log_e (D_p/d_p)} \qquad (21)$$

Since the work done on the oil is a function of P and Q, only the temperature rise will be given by Equation (13). When one plate is rotating with respect to the other, the rate of doing work in shearing the oil film will be

$$H = \frac{\pi^3 N^2 (D_p^4 - d_p^4)\mu}{8C} \qquad (22)$$

To compute the flow through a tube of length L and circular cross-section of diameter D, the Poiseuille equation is used:

$$Q = \frac{\pi}{128} \frac{D^4 P}{\mu L} \qquad (23)$$

When the pressures are high enough to cause an appreciable change in viscosity,

Table II—Conversion Factors for Fluid Density

Specific gravity, 60/60	Deg., A. P. I. gravity	Cu. in. per lb.	Cu. in. per gram	Gal. per lb.	Lb. per cu. in.	Grams per cu. in.	Lb. per gal.
0.75	57.17	37.01	0.08159	0.1602	0.02704	12.28	6.244
0.76	54.68	36.50	0.08047	0.1580	0.02740	12.43	6.327
0.77	52.27	36.04	0.07945	0.1560	0.02776	12.59	6.410
0.78	49.91	35.57	0.07842	0.1540	0.02812	12.75	6.494
0.79	47.61	35.11	0.07740	0.1520	0.02848	12.92	6.577
0.80	45.38	34.67	0.07643	0.1501	0.02884	13.08	6.661
0.81	43.19	34.26	0.07533	0.1483	0.02920	13.24	6.744
0.82	41.06	33.84	0.07460	0.1465	0.02956	13.40	6.827
0.83	38.98	33.43	0.07370	0.1447	0.02992	13.57	6.911
0.84	36.95	33.03	0.07282	0.1430	0.03028	13.73	6.994
0.85	34.97	32.64	0.07196	0.1413	0.03064	13.90	7.078
0.86	33.03	32.25	0.07110	0.1396	0.03100	14.06	7.161
0.87	31.14	31.88	0.07028	0.1380	0.03136	14.22	7.244
0.88	29.30	31.49	0.06942	0.1365	0.03172	14.39	7.328
0.89	27.49	31.16	0.06870	0.1349	0.03208	14.55	7.411
0.90	25.72	30.82	0.06795	0.1334	0.03245	14.72	7.494
0.91	23.99	30.49	0.06722	0.1320	0.03281	14.88	7.578
0.92	22.30	30.15	0.06647	0.1305	0.03317	15.04	7.661
0.93	20.65	29.82	0.06574	0.1291	0.03353	15.21	7.745
0.94	19.03	29.52	0.06508	0.1278	0.03389	15.37	7.828
0.95	17.45	29.20	0.06439	0.1264	0.03425	15.53	7.911
0.96	15.90	28.90	0.06371	0.1251	0.03461	15.70	7.995
0.97	14.38	28.60	0.06305	0.1238	0.03497	15.86	8.078
0.98	12.89	28.30	0.06239	0.1225	0.03533	16.02	8.162
0.99	11.43	28.02	0.06177	0.1213	0.03569	16.18	8.245
1.00	10.00	27.74	0.06116	0.1201	0.03605	16.35	8.328

where P_1 is the pressure at the inlet and P_2 the pressure at the outlet of the tube, the expression becomes

$$Q = \frac{\pi}{128}\frac{D^4}{\mu_o L}\frac{1}{b}\left(e^{-bP_2} - e^{-bP_1}\right) \qquad (24)$$

All of the preceding discussion has assumed mathematically perfect geometric surfaces and retention of dimensions. But dimensional changes can be expected as a result of temperature and pressure deformation, and machining tolerances can cause variations in the geometric form.

Dimensional changes caused by temperature changes will be of significance only when the piston and cylinder are made of materials having different thermal coefficients of expansion. If the coefficient of expansion of the piston is α and that of the cylinder is β, and the clearance is C_o at a reference temperature t_o, the clearance at other temperatures will be

$$C = C_o + d_p\,(\beta - \alpha)\,(t - t_o) \qquad (25)$$

By deliberately selecting materials of different coefficients of expansion, it is possible to control the leakage rate over a substantial temperature range with some degree of success. As an example, suppose it is desirable to have the same leakage rate at two different temperature t_1 and t_2, the latter being the higher temperature. Let the corresponding viscosities at those temperatures be μ_1 and μ_2, and the clearances be C_1 and C_2. Then

$$C_1 = C_o + d_p\,(\beta - \alpha)\,(t_1 - t_o)$$
$$C_2 = C_o + d_p\,(\beta - \alpha)\,(t_2 - t_o)$$

and since the flows are to be equal

$$Q_1 = Q_2 = \frac{\pi C_1^3 P}{96\mu_1 L} = \frac{\pi C_2^3 P}{96\mu_2 L} \qquad (26)$$

or

$$\frac{C_1}{C_2} = \frac{C_o + d_p\,(\beta - \alpha)\,(t_1 - t_o)}{C_o + d_p\,(\beta - \alpha)\,(t_2 - t_o)} = \left(\frac{\mu_1}{\mu_2}\right)^{1/3} \qquad (27)$$

or

$$\beta - \alpha = \frac{C_o\left[(\mu_1/\mu_2)^{1/3} - 1\right]}{d_p\left[(t_1 - t_o) - (t_2 - t_o)\,(\mu_1/\mu_2)^{1/3}\right]} \qquad (28)$$

Suppose it is desired to hold the leakage constant at 100 and 210 deg. F., using an oil that has 23 times the viscosity at 100 deg. F. that it has at 210 deg. F., that the clearance is C_o at 100 deg. F., and that the piston diameter is 0.5 inch.

Substitution of these data into Equation (28) shows that α minus β must equal 0.01 C_o to produce the desired compensation. The clearance would then be chosen to produce the desired leakage at 100 deg. F. As the temperature increases the flow will increase to a maximum and then start falling until at 210 deg. F. it equals the flow at 100 deg. F. This behavior is illustrated in Fig. 8, which shows the ratio of the flow at different temperatures to the flow at 100 deg. F. plotted against the temperature. The flow at 210 deg. F. would be 23 times that at 100 deg. F. without this compensation for expansion.

Dimensional changes can be expected as a result of the internal pressure that compresses the piston expands the cylinder. Because of the pressure drop along the seal, the change in clearance will decrease from inlet to outlet.

Where

E = Young's modulus
A = outside dia. of cylinder, in.
D = piston dia., in.
P = pressure, lb. per sq. in.

The change in clearance caused by the dimensional changes in both piston and cylinder is

$$\Delta C = \frac{DP}{E}\left(\frac{2A^2}{A^2 - D^2}\right) \qquad (29)$$

For a rotating shaft emerging from a pump or motor housing, it should be noted that while the equations give a rise in temperature for the heat developed in the oil film by the rotating shaft, they do not take account of the preceding history of the oil inside the pump. Usually in rotary pumps or motors there will be a pair of rotating disk surfaces at each end of the pump formed by the side of the drum and vanes in a vane type pump or the sides of the gears in the gear type. There is a flow across these surfaces from discharge toward suction side of the pump, and the oil is heated in this capillary space by the shear. This oil, some of which will finally leak out at the shaft capillary seal, has already been heated above the system temperature.

The value of this rise in the design of rotary pumps has been computed by R. J. S. Pigott of the Gulf Research & Development Company. It is a somewhat tedious procedure, particularly as the paths for flow differ with the different pump designs. But at this stage of development, it is not considered necessary to take this additional correction into account, because the rotating shaft of a hydraulic pump or motor running at fairly high speeds is the one design where complete eccentricity of the shaft in the lap fit is not likely to be encountered. The maximum flow, therefore, that results from complete eccentricity will seldom or never be present. This condition probably will more than counterbalance neglecting to account for the heating of the oil inside the pump.

When considering leakage caused by vibration, the minimum condition for the leakage is concentricity, the maximum is complete eccentricity. With vibration, there can be no design that does not lie between these two limits, therefore, the flow when vibration is present must also lie between the computed maximum and minimum. In general, when in operation it is not possible to predict what the attitude will be of one member lying inside another with a lapped fit. Therefore, the engineer can concern himself only with the maximum condition that might possibly occur occasionally, with the knowledge that all actual average flow will be less than for that condition.

The difficulty in computing flows through capillary seals is largely that of getting precise dimensions of the parts, and also the variation of flow that occurs because of differences in eccentricity, or attitude. One convenience is that the character of the surfaces in viscous flow has little effect upon the rate of flow as distinguished from its effect in the turbulent regions. In addition, the use of lapped fits will practically standardize all surfaces, since the mere operation of suitable lapping will bring roughness within a narrow range of values.

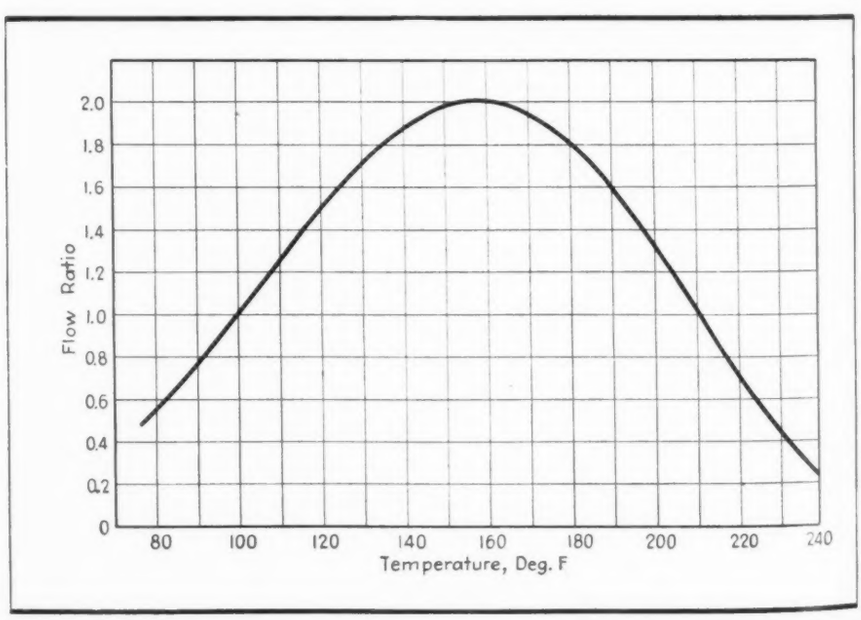


Fig. 8—Ratio of flow at different temperatures to flow at 100 deg. F. plotted against temperature.

New Materials and Techniques Broaden Plastics Applications

Wartime performance requirements, which greatly accelerated progress in materials research and stimulated improvements in production techniques, had important effects in the field of plastics. New plastics with interesting properties were developed, new processing methods were devised and standard techniques were improved. Many applications, in hitherto untried fields, resulted. A brief resumé and specific data on certain of the developments are given on the following pages. Future issues will include articles on additional materials and techniques, as data are released. An index of plastics design articles which have appeared in Product Engineering during the war years is included.

IN THE FIELD of plastic materials research concentrated on improvements in existing materials, emphasizing increased heat and moisture resistance, and better strength and flow characteristics. Several new materials reached commercial development. Specific developments of interest to the engineer are mentioned briefly.

POLYETHYLENE—This high-frequency dielectric material was originally developed for wire and cable insulation. It has flexibility and toughness over a wide range of temperature, low-water absorption and chemical inertness.

CELLULOSE PROPIONATE. A new cellulose-base plastic having advantages in low moisture sensitivity and greater inherent plasticity, which give it better dimensional stability as compared with the acetates.

SILICONE MATERIALS. Developed basically from an organic-inorganic polymer in which silicon atoms carry one or more hydrocarbon groups. The materials have high heat resistance and excellent electrical insulation properties. Liquid types show little or no change in viscosity over wide temperature ranges. Forms available include compounds and greases, fluids, varnishes and resins, and elastic materials.

MELAMINES. Basically manufactured from a trimer of cyanamid and formaldehyde, these materials exhibit good arc resistance and impact strength, and are available in a variety of colors.

ALLYL RESINS. Thermosetting materials derived from allyl alcohol or chloride, and cured by polymerization. Properties lie between those of the thermosets and the thermoplastics.

STYRENE. New copolymers, having higher heat distortion temperatures recently reached commercial development. Styrene was also applied in contact pressure laminating, in foamed resins, and in oriented matted fibers for low-pressure bag molding.

OTHER DEVELOPMENTS. Vinyl materials underwent numerous refinements, and were used in new applications capitalizing on their elastomeric qualities. In the cellulosic plastics, flame-resistant molding compositions and carboxymexyl cellulose were developed. Thermoplastic laminates were also successfully made. In the phenolic fields, special attention was given to fillers imparting high impact strength, such as chopped tire cord. Extensive use was made of phenolic casting resins as foundry patterns, dies and fixtures. Colored methyl methacrylate also became available. Progress was made in the extrusion, injection and compression molding of nylon compounds.

New Techniques and Machines

As mentioned previously, improvements in processing and in machines kept pace with other war-stimulated developments in the industry. Among these can be mentioned high-frequency electrostatic heating, postworming of laminates, contact pressure lamination, cellular laminates, friction welding, expanded resins, plunger molding, combined injection-compression molding of thermoplastics, blow molding, wood molding, and continuous extrusion of thermosetting materials.

HIGH-FREQUENCY HEATING. First announced several years ago, this method has undergone numerous refinements and has made possible the molding of large, thick pieces. Molding machines incorporating this principle are under development.

POSTFORMING OF LAMINATES. Developed originally by the aircraft industry, this method, which utilizes inexpensive molds, is gaining wide acceptance for semi-structural and non-structural parts of complex shape where a combination of strength

and lightweight is desired. Flat sheets are preheated and formed over wooden molds at pressures higher than 1,000 lb per sq. in. Developments in special laminating fabrics are now under way.

LOW-PRESSURE LAMINATE MOLDING. Resins of the styrene-polyester, phenolic, allyl and the ethyl cellulose type are used in fabrication and forming of lightweight structures at pressures below 500 lb. per sq. in. and generally below 100 lb. per sq. in., utilizing the rubber-bag technique. Molds are cast materials, wood, or plaster of paris. Special filler materials are available. These include Mitscherlich paper, woven-glass fiber and sisal. Strength properties of the low pressure phenolic and styrene-polyester fiberglass laminates, particularly impact, tensile, compressive and flexural, approach values which are of direct interest for structural design, although moduli of elasticity are low. Density approximates half that of aluminum and one-fifth that of steel.

CELLULAR LAMINATES. High-strength sandwiched materials, foamed resins, blown rubber, and balsa wood surfaced on top and bottom with sheets of low pressure laminated materials, were developed. These were specifically used in the aircraft field.

FRICTION WELDING. A new technique of bonding thermoplastic to thermoplastic, or thermoplastic to other materials, reached commercial development during 1945. In this technique the material is spun at high speed while in contact with the mating material. The frictional heat developed is sufficient to weld the two together. An ordinary drill press can be utilized in the process.

EXPANDED RESINS. Chemical activation to cause foaming of phenolics and styrene polyester resins into cellular structures which are non permeaable and of low density. These materials, which are excellent heat insulating mediums, can be expanded in place in the structure. They are first poured in as liquids and as they foam they fill the space between the walls with a rigid lightweight porous mass, which not only adds to the strength but furnishes high heat insulating value.

PLUNGER MOLDING. A new machine developed in 1945 combined high-frequency pre-heating, a pressure-type transfer mold and a press with an auxiliary downward acting plunger. The plunger forces the pre-heated plastic to the bottom of a transfer pot while, by means of a pressure pad, it is deflected at wide angles along runners and gates into the cavities. This operation takes only a few seconds. The thin orifices between the runners of the cavity in the specially designed molds act as pressure reducing valves and cause a rise in temperature of the material, thus reducing curing time, it is claimed.

COMBINED INJECTION - COMPRESSION MOLDING. Another new machine incorporates both types of molding in one form, thus permitting the application of both techniques to thermoplastic molding. The advantages of injection molding, such as absence of flash and speed of producton, are combined with the advantages of high pressure obtained by the compression stroke. The gates are removed automatically by the action of the machine. The machine is particularly advantageous for the production of heavy-sectioned thermoplastic parts.

BLOW MOLDING. Hollow articles are now being molded by the blowing technique by two methods. In the first method a rod, sheet or tube is blanked out, reheated and blown to final shape. In another method, molding material is plasticized, formed into an intermediate shape and then blown into final shape.

WOOD MOLDING. Wood is placed in an impregnation chamber under vacuum. Then, after all air has been removed, resin is admitted to the chamber and pressure raised to 150 to 350 lb. per sq. in. After removal, the pre-forms are air dried and then formed to shape. The solid pre-forms are first roughly formed to shape.

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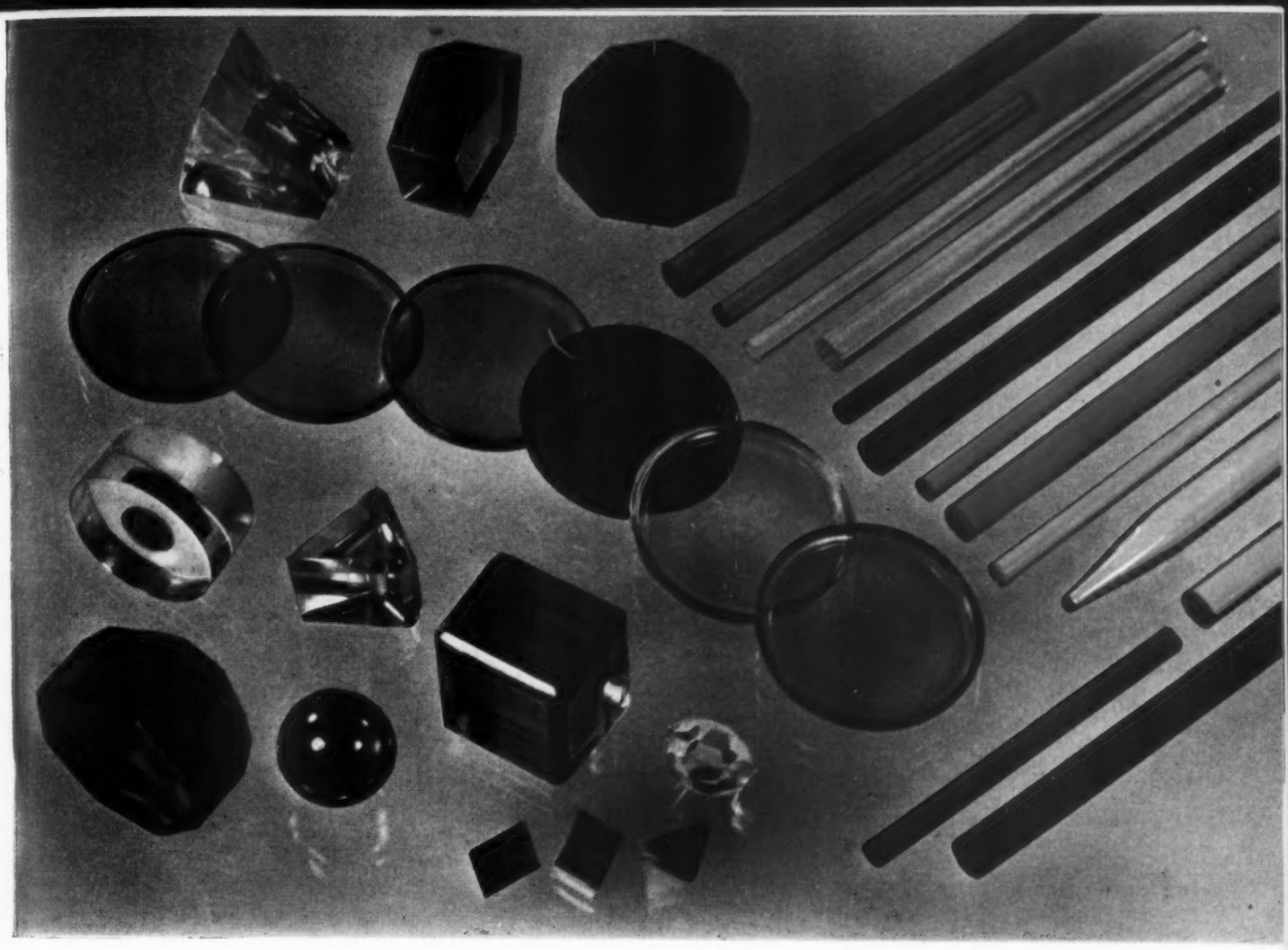


Gem-like color is obtained in castings and machined shapes of Kriston.

ALLYL RESINS

New thermosetting material, easily processed, offers advantages in optical, electrical and chemical properties.

THIS NEW SERIES of thermosetting plastics materials, the first member of which is a monomeric allyl ester, when polymerized under heat and a catalyst provides a material which combines electrical, optical and chemical properties with high heat and flame-resistance.

Optical properties are particularly interesting. Approximately one-half as heavy as glass, the material can be ground and polished much more easily. Excellent clarity and less light dispersion than most optical glass are characteristics of this new plastic. Refractive index is 1.57, hence it is a promising material for lenses, prisms, reflectors and refractors. Lenses have been ground to perfect correction on regular equipment and at a considerable saving of time. For optical uses where great precision is not required, parts may be cast so that very little or no finishing is necessary. Some suggested products are optical contact lenses, viewing glasses in chemical process control instruments, cast camera lenses, window display stands, illuminated sign parts, or other applications where beauty, transparency or translucency of the end product is a requisite.

Electrical and physical properties at high temperatures plus chemical resistance at normal temperatures suggest applications in the electrical industry, particularly in appliances where rigid or semi-rigid insulating members may be required, such as control panels, rigid insulating sheets or separators, control knobs, or cast parts for switches, fuse boxes, amplifiers and similar equipment. An insulator showed tracking at 27,000 volts, whereas the porcelain insulator tracked at 31,000 volts. There was no carbonization on instantaneous flash-over.

Actual properties of a Kriston monomer, polymerized under controlled conditions to a uniform hardness of 40 as measured by the Barcol Impressor and without coloring or extending agents, are shown in the table. Where a range of values is shown for a property, the data indicate the maximum and minimum which may be obtained by varying the degree of polymerization.

Colors

Although the polymer in the natural state is crystal clear, it may be produced in transparent, translucent or opaque colors. Transparent coloring may be achieved either by dyeing the polymer or preferably, by dyeing the monomer before casting. In the

Based on data prepared by S. L. Brous, Goodrich Chemical Co.

latter case, the dyes must be chosen carefully so that they do not materially influence the polymerization reaction.

Dyes in transparent colors have been tested, and satisfactory dyes for the following colors have been found: yellow, medium red, dark red, red, rose, green, blue-green and purple.

Translucent, opaque and luminescent colors are obtained by proper pigmentation of the monomer before it is cast. In these cases, too, some measure of care should be exercised in the choice of coloring agents. Such pigments as titanium dioxide, antimony oxide, talc and barytes have been used with reasonable success.

Another property, not mentioned previously, is that of low heat conductivity.

Processing consists of four steps: preparation of the catalyst; preparation of monomer-catalyst system; polymerization or "cure"; and finishing, if any is required, of the product, which may include cutting, sanding and polishing.

Polymerization and Cure

The polymerization of Kriston monomer is a heating operation requiring a temperature and period of heating which depend on the size and shape of the casting. If an ordinary casting is to be made, the catalyzed monomer, preferably pre-heated to 70 deg. C. is poured into the mold and the whole treated in an oven or otherwise at the same temperature, 70 deg. C. until all air bubbles have risen to the surface and broken. Mold covers or inserts, if any, should be carefully placed to avoid any entrapment of air. If the surface is to be left free, cellophane or other similar materials is laid carefully on top to exclude all air from the monomer. Heating is then continued until polymerization has been completed.

This heating step varies in procedure according to the casting because the polymerization of Kriston monomer involves an exothermic reaction with heat given off at a rate dependent on the exterior temperature, the thermal conductivity of the mold material and the catalyst concentration. Because of that and the fact that organic materials are poor heat conductors, the polymerization conditions will vary as the size and shape of the casting change. If the internal heat of polymerization is not dissipated, it will build up and accelerate the liberation of still more heat, the reaction becoming autocatalytic. Under such conditions, the resulting polymer shows evidence of cracks or stains and non-homogeneity.

The larger the size of the casting, the more difficult becomes the matter of heat dissipation. Accordingly, the cure of large thick castings must be conducted at lower exterior temperatures than those required for thin castings.

After the polymerization has been completed, the casting is ready for removal from the mold. Gradual cooling insures a strain-free product.

Table of Properties

Specific gravity (A.S.T.M. D 792-44T)	1.34-1.40
Flammability, in./min. (A.S.T.M. D 635-41T)	self-extinguishing
Coefficient of linear expansion (A.S.T.M. D 696-44)	5.45 x 10^{-5}
Refractive index, 20/D (A.S.T.M. D 542-42)	1.57
Hardness, Rockwell M. (A.S.T.M. D 785-44T)	116
Compressive strength, lb. per sq. in. (A.S.T.M. D 695-42T)	19,600
Specific heat, Cals./gm./deg. C.	0.26
Heat distortion point, deg. F. (A.S.T.M. D 648-45T)	
@ 66 lb. per sq. in. fiber stress	226
@264 lb. per sq. in. fiber stress	190
Dielectric strength, v.p.m. (A.S.T.M. D 149-40T) (step-by-step —0.017 in. thickness)	1,275

Dielectric constant and Loss factor (A.S.T.M. D 150-42T)

Temp. deg. C.	Dielectric Constant 60 cyc/sec	1,000 cyc/sec	10,000 cyc/sec	Loss Factor 60 cyc/sec	1,000 cyc/sec	10,000 cyc/sec
—10	3.26	3.18	3.13	0.0417	0.0404	0.0592
0	3.31	3.23	3.16	0.0487	0.0452	0.0609
10	3.37	3.27	3.21	0.0652	0.0503	0.0559
20	3.45	3.33	3.25	0.0668	0.0576	0.0579
30	3.51	3.39	3.30	0.0732	0.0632	0.0668
40	3.61	3.46	3.36	0.0831	0.0757	0.0763
50	3.68	3.52	3.41	0.0883	0.0831	0.0832
60	3.79	3.63	3.49	0.0910	0.0929	0.0935
70	3.89	3.71	3.56	0.0953	0.100	0.105
80	3.92	3.76	3.63	0.0825	0.0985	0.107
90	3.98	3.79	3.62	0.0744	0.0947	0.101
100	3.90	3.77	3.62	0.0663	0.0880	0.0998
110	3.93	3.82	3.62	0.0589	0.0803	0.106
120	4.00	3.88	3.75	0.0603	0.0815	0.101
130	4.10	3.97	3.83	0.0615	0.0852	0.107
140	4.20	4.06	3.91	0.0630	0.0853	0.109

Volume resistivity, x 10^{14} ohm-cms (A.S.T.M. D 257-38)

a. Over the range — 10 deg. C. to + 110 deg. C.	Too high to measure
b. At 120 deg. C.	5.8
c. At 130 deg. C.	5.2
d. At 140 deg. C.	2.2

Effect of Chemicals

Sample In	Weight Change Percent Gain (+) or Loss (—)
Sulfuric acid 3 percent	+0.13
Sodium hydroxide 10 percent	—0.11
Nitric acid 10 percent	+0.12
Acetic acid 5 percent	+0.15
Sulfuric acid 30 percent	+0.07
Hydrochloric acid 10 percent	+0.13
Sodium hydroxide 1 percent	+0.13
Sodium chloride 10 percent	+0.13
Sodium carbonate 10 percent	+0.14
Ethyl alcohol 95 percent	+0.32
Ethyl alcohol 50 percent	+0.23
Oleic acid	+0.02
Distilled water	+0.14
Hydrogen peroxide 3 percent	+0.16
Gasoline	+0.15
Hydrofluoric acid 15 percent	+0.11

No dimensional changes observed

A field that offers possibilities in the near future is that in laminated structures. Glass wool, glass fabric, cotton fabric, paper, asbestos and wool have been laminated with Knsten by conventional methods and with very interesting results.

Shrinkage on polymerization from monomer at room temperature to polymer at room temperature is 3.25 to 7 percent, depending on degrees of polymerization.

Molds

Molds can be constructed from ferrous and non-ferrous metals, glass or densely cast plaster of paris. Glass molds serve exceptionally well but are subject, of course, to inherent hazards. Although neither glass nor metal molds seem to require lubrication, the use of very light films of paraffin appears to be advantageous. The plaster of paris mold is coated with a solution of nitro cellulose acetate and subsequently lubricated with mineral oil.

When casting objects having undercutting or re-entrant angles, low melting alloys such as Wood's or Rose metal should be used for the mold. Any of the metal then retained in the undercuttings or re-entrant angles can be removed easily by melting the metal in boiling water. No damage results to the casting. In using molds of this type alloy, polymerization of the monomer is effected at temperatures just below the melting point of the metal.

Where attractiveness and light reflecting qualities are especially important, polished glass or metal molds will produce the desired surfaces.

When a product proves difficult to cast to final shape because of an unusual contour, two steps are used. The first is to cast and partially polymerize flat sheets to a relatively soft non-tacky state. The second is to bend the soft flat sheet to the required form on a mandrel or other suitable device, then harden by further heating. As in conventional type of casting, atmospheric oxygen must be excluded to complete the cure.

MODIFIED STYRENES

Improvements in heat resistance, strength and other properties are achieved in new materials based on modifications of polystyrene.

EFFORTS to develop injection molding materials of higher heat resistance have centered on polystyrene because of its general availability and low cost. Several methods have been used: copolymerization of styrene with other components, modification of the molecule by adding chlorine; special polymerization techniques in production.

Recent materials stemming from these investigations are Cerex, polydichlorostyrene, and certain modified styrenes such as Dow Q247, and Textolite 1421. Latest material to be announced is Rohm and Haas' Plexene M, properties of which are tabulated below.

Cerex is the designation of a series of new thermoplastic compounds, copolymers of styrene with ASTM heat distortion points of 212 to 256 deg. F. Development has been concentrated on Cerex X214, with an ASTM heat distortion point of 220 to 230 deg. F.

Parts molded to close dimensional tolerances maintain dimensions and mechanical strength during prolonged exposure at temperatures over the boiling point of water. Parts molded of the new plastic may be sterilized in boiling water or used at ambient temperatures in a range hitherto restricted to thermosetting plastics.

Polydichlorostyrene is a thermoplastic molding compound with an ASTM heat distortion point of 236 deg. F. as compared to 173 deg. F. in polystyrene. This brings it above the operating temperatures of radio and other electronic instruments. The added heat resistance has been secured with a slight improvement in loss factor over polystyrene.

Physically, polydichlorostyrene resembles polystyrene. It is crystal clear and molds readily. It is not expected to become a material of broad use because of very high manufacturing costs, arising from a many-

Properties of Plexene M

Property	Test Method	Test Conditions	Data
Specific Gravity	A.S.T.M. D71-27		1.08
Tensile strength lb. per sq. in.	A.S.T.M. D638-42T	1/8 in. max. 1/8 in. rupture 1/4 in. max. 1/4 in. rupture	10,000 10,000 10,000 10,000
Flexural strength lb. per sq. in.	A.S.T.M. D650-41T	maximum rupture modulus elasticity deflection	16,000 16,000 550,000 0.2 in.
Compressive lb. per sq. in.	A.S.T.M. D695-42T		15,000
Impact	A.S.T.M. D256-41T	unnotched (1/2x1/2 in. section) notched (per inch molded notch)	3.2 ft. lb. 1.0 ft. lb.
Heat Distortion	A.S.T.M. D648-45	1/2 deg. C./min.-264 lb. per sq. in. 2 deg. C./min.-264 lb. per sq. in. 2 deg. C./min.-66 lb. per sq. in.	85 deg. C. (185 deg. F.) 90 deg. C. (194 deg. F.) 102 deg. C. (216 deg. F.)
Flow Temperature	A.S.T.M. D569-43	At 1,500 lb. per sq. in.	145 + 5 deg. C. (293 + 9 deg. F.)
Shrinkage of Injection Molded Bar	Air oven heating	2 hr. at 80 deg. C. 2 hr. at 90 deg. C. 2 hr. at 100 deg. C.	0.2 mils per in. (0.0002 in./in.) 0.5 mils per in. (0.0005 in./in.) 6.0 mils per in. (0.0060 in./in.)
Abrasion Resistance	LP406a	CS 10/500g. 25 revs. (Percent Parallel) (Light Trans.)	11 percent
Light Transmission percent	A.S.T.M. D672-42T	parallel total White haze	49 57 15
Accelerated Weathering	LP-406a-6021 (200 hr.)	crazing discoloration warping unmolding	None None None None
Dielectric Strength at 25 deg. C., volts per mil	A.S.T.M. D149-40T	Short Time Test	350 + 25
Dielectric Constant at 25 deg. C.	A.S.T.M. D150-42T	60 cycles Bridge Method 1,000 cycles Bridged Method 1,000,000 cycles Susceptance Method	3.0 + 0.3 3.0 + 0.3 3.0 + 0.3
Power Factor percent at 25 deg. C.		60 cycles Bridge Method 1,000 cycles Bridge Method 1,000,000 cycles Susceptance Method	1.0 + 0.3 0.8 + 0.3 1.0 + 0.3
Arc Resistance	A.S.T.M. D 495-42		140 + 10 sec.
Loss Factor	A.S.T.M. D150-42T	60 cycles Bridge Method 1,000 cycles Bridge Method 1,000,000 cycles Susceptance Method	0.17 − 0.23 0.16 − 0.21 0.06 − 0.09
Burning Rate			Slow
Odor			None

stepped process, with relatively low yield at each step. Equipment required is elaborate and expensive.

Modified Styrene

In this modified styrene compound, Q247 (Dow) an increase of 10 to 15 deg. F. in heat distortion point has been achieved without sacrifice of any of the other properties of polystyrene. Depending on shape, size, and molded-in strains, parts of the material may be subjected to boiling water for varying intervals up to 20 min. The material may thus be considered as intermediate in heat resistance among injection-molding materials between polystyrene and other new modified styrene materials.

Mechanically, the properties of the new material are somewhat improved over polystyrene, tensile strength being about 25 percent higher and flexural and shock strength somewhat better.

Thermosetting Copolymer

This copolymer, Textolite 1421, represents one attempt to retain the electrical properties of the styrene resins in a material of higher heat resistance. The material is a copolymer of undisclosed components which is poured into rod or sheet form as a liquid monomer or sirup and then subjected to a baking cycle which cures it into a thermoset, nonsoftening transparent resin. Finished parts are produced by machining from standard rods or sheets. Since it is thermosetting and the curing is a matter of hours, it is not applicable as a molding material.

Although the ASTM heat distortion point is in the same range as polystyrene, the material does not soften rapidly after the temperature is raised past the heat distortion point. Under no load, the copolymer retains its form at temperatures up to 390 deg. F.

CELLULOSE PROPIONATE

Good dimensional stability, high impact strength, high surface finish feature this newest cellulose plastic.

CHEMICALLY SPEAKING, this new material is a cellulose propionate flake suitably plasticized and resulting from the reaction of propionic acid and propionic anhydride with cellulose in the presence of a suitable catalyst. Its chemistry is well known and many of the properties that exist were expected of the cellulose propionate plastic, purely from the chemical structure. An examination of the chemical formulae shows that cellulose propionate, in terms of carbon atoms, lies between cellulose acetate and cellulose butyrate. Thus, it should have even more promising possibilities as a plastic raw material.

Stability relationship in the fatty acid esters series show that cellulose propionate should be an unusually stable plastic. From experimental tests and industrial evaluation, this factor has been established as one of its important advantages over existing thermoplastics. Following this stability quality, the odor-free nature of the molded plastic parts further establish this characteristic. Even during molding operations at high temperature, no objectionable odor is given off.

Considering aging qualities, the material has good aging characteristics based on the fact that the nature of cellulose propionate makes possible very low plasticizer levels compared to cellulose acetate for the same strengths. This relationship is related to the difference in rigidity as the carbon chains of the esterifying acid are increased. Cellulose propionate requires less plasticizer.

High impact strength in the region of moderate plasticizer levels is unusual and is one of the important properties. This high impact characteristic is not confined to the soft formulas, but is available where dimensional stability and stiffness are required.

Humidity expansion is low and the effect of water absorption on the finished molded piece is small, resulting in low warpage and excellent dimensional stability. Considering the specific gravity of 1.17 to 1.22, one can easily see that a saving over cellulose acetate on a weight basis is possible.

Other properties such as tensile, flexural and compressive strengths, heat distortion point, cold flow, cover about the same range as the other cellulose esters. Electrical properties are in the same good range as the acetates and in some respects better. Because of the low moisture absorption electrical properties are not as easily affected by atmospheric changes. Other characteristics are high dielectric strength, but low power factor and dielectric constant. Already a complete range of opaques, transparents and translucents are available with eventually the unlimited colorability of the acetates being made available to industry.

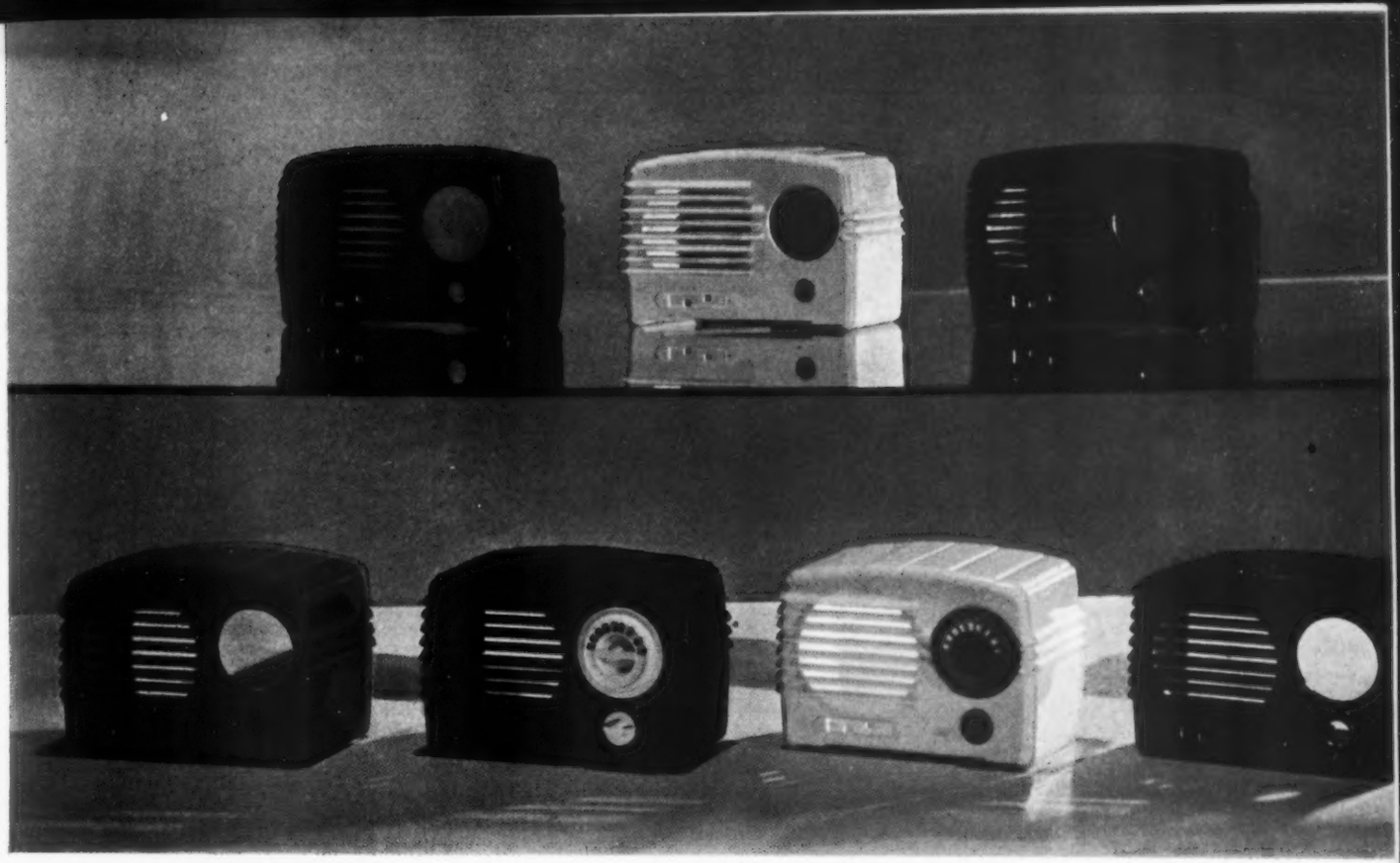
Industrial Evaluation

In the first commercial moldings an unexpected quality, high surface finish, was obtained. This finish was so high and free

Table of Properties

Property	ASTM Method	Unit	Typical Composition	Typical Composition
Flow temperature	D569-43	deg. C.	169.5	161.5
Specific gravity	D176-42T	gms./cc.	1.21	1.19
Rockwell hardness	D229-43	R Scale	111.	97
Impact strength (Izod)	D256-43T	ft. lb./in. of Notch		
		25 deg. C.	1.4	7.8
		− 40 deg. C.	0.75	0.8
Distortion under heat	D648-41T	deg. C.	64	62
Tensile strength	D638-42T	lb./sq. in.	5,095	4,070
Elongation	D638-42T	Percent	41	35
Flexural strength	D650-42T	lb. per sq. in.	8,430	6,730
Water absorption (24 hr. immersion)	D570-42	percent	1.6	1.4
Soluble matter lost (24 hr. immersion)	D570-42	percent	None	None
Weight loss on heating (72 hr. at 82 deg. C.)	D706-43T	percent	0.5	1.5
Power factor	D150-42T		0.020	0.021
Dielectric constant at 1 megacycle	D150-42T		3.37	3.40

Based on data prepared by W. Ward Jackson, Celanese Plastics Corp.



High surface finish is a characteristic of Forticel, which like other thermoplastics, is available in a wide range of colors

Good mold finish and good dimensional stability of Forticel plastic are advantages in this all-molded flashlight

from smudge and cloud that many parts that had previously been buffed now required no further finishing. This factor is important when possible cost savings are considered. On several of the early molding tests, it was found that satisfactory pieces could be molded within a wide temperature range, in some cases over a range of 80 deg. F. Apparently the material softens more quickly and flows easier than other cellulosics.

Extensive tests made on the effects of temperature on the molded part, showed that this material readily fills dies with small gates and has good welding qualities at the same time. Actually less evidence of weld lines existed in early tests than on any other cellulosic molded in the same part. In later tests with new formula these welds were not only strong and the parts free from smudges and surface conditions, but the weld lines were invisible.

One of the important factors which turned up on comparison in a number of different type dies on several different machines was the lowered overall cycle that could be obtained. Although not always an advantage due to the mechanics of certain dies having extensive inserts, in many cases cycles were lowered 30 percent or more.

On a typical test the following conditions were observed:

Trial X Molding Cycle	Forticel	Competitive Cellulosic
Injection—sec.	8	11
Die Clamp	6	12
Die Opening	4	6
Overall	18	29
Percent reduction in sec.	37.9 percent	

Similarly

TRIAL Y	Forticel	Competitive Cellulosic
Nozzle deg. F.	470	420 deg.
Main cylinder deg. F.	460	410 deg.
Back cylinder deg. F.	390	350 deg.
Injection pressure, lb. per sq. in.	500	800
Injection time in sec.	17 sec.	17 sec.
Die closed	7 sec.	15 sec.
Die open	5 sec.	5 sec.
Overall	29 sec.	37 sec.
Percent reduction in cycle	21.6 percent	

The balance of properties permits a greater versatility of qualities in the finished article, lowered cost and faster production per molding unit. It must be cautioned that there may be exceptions to some properties on individual parts. It is expected that films and foils, as well as sheets, rods and tubes will be available.

SILICONE MATERIALS

Organo-silicone polymers of high heat resistance are available as fluids, greases, insulation and elastomers.

Silastic, a silicone elastomer, is extruded in conventional equipment. The material is fed in the form of crepe into the machine.

ANY NEW MATERIAL with properties different from those of previously available materials offers the possibility of design improvements and economies. Such new materials are the silicones, basically organo-silicon polymers, available in numerous forms, having high heat stability as compared with conventional organic products. The properties of heat resistance, inertness and excellent dielectric properties derive from the fact that these new materials are built up on a silicon-oxygen-silicon structure which provides characteristics similar to those of quartz, glass and asbestos. Forms available include resins; fluids that do not thicken at low temperatures and do not decompose at high temperatures; electrical insulation that withstands extreme temperature and humidity conditions; paints that do not change color or lose, at high temperatures, their ability to protect surfaces from corrosion; and rubber that does not harden and crack on long exposure to high temperature.

Silicone Fluids

Silicone fluids are a group of liquids having high heat stability, inertness, good electrical properties, and insolubility in water. Several types of silicone fluids are available to meet a variety of special applications. *DC 500 Fluids*, for use from below —70 deg. F. to above 200 deg. F. are available in viscosity grades ranging from 0.65 to 50 centistrokes. They are waterwhite, inert liquids characterized by flat viscosity-temperature slopes, heat stability, oxidation resistance, and waterproofness.

DC 200 Fluids, for use from —40 deg. F. to 400 deg. F. are available in a wide range of viscosities from medium to very high. DC 200 Fluids are characterized by: low viscosity-temperature slope; high flash and fire points; low volatility and negligible vapor pressure; oxidation resistance; lack of color, odor, and toxicity; and low power factor.

DC 710 Fluids for high temperature lubrication are heat stable, inert lubricants for service at temperatures beyond the range of most organic lubricants. They remain liquid down to —15 deg. C. and are useful up to 260 deg. C. The high flash points, low volatility and freedom from gumming make them useful at elevated temperatures.

Silicone Greases and Compounds

DC 4 Ignition Sealing Compound

This insulating compound is a waterproofing and sealing agent for the ignition systems of aircraft, tanks and similar vehicles. It is non-melting, oxygen resistant and has a very low freezing point, and also serves as an auxiliary dielectric and waterproofing seal for disconnect junctions in radio communication and radar systems. Dielectric constant is 2.8 over a wide frequency spectrum, and power factor is less than 0.05 percent up to 1 megacycle. Dielectric strength is 500 volts per mil at 10 mils and volume resistivity is greater than 10^{14} ohm cms. at 25 deg. C. and 10^{12} ohm cms. at 200 deg. C.

Lubricating Greases

Three silicone greases have been developed, for the lubrication of ball bearings operating at abnormally high and low temperatures. They are characterized by a high order of heat stability, low volatility, relatively slight changes in consistency over a wide temperature range, and low freezing points.

DC 33, a silicone grease thickened with metallic soaps, is used for low temperature lubrication of bearings operating at speeds up to 10,000 r.p.m. It is serviceable over a temperature range of —95 deg. F. to 300 deg. F.

DC 41, developed for the lubrication of bearings operating at elevated temperature and at speeds of less than 4000 r.p.m., is an almost completely inorganic grease, and does not melt at temperatures in excess of 480 deg. F. More frequent lubrication is required at temperatures above 300 deg. F. because of increased bleeding. Extreme heat resistance recommends it for special applications such as the lubrication of pumps handling molten salts and over machinery.

DC 44 is a silicone grease thickened with metallic soap for the high temperature lubrication of bearings operating at speeds up to 10,000 r.p.m. It is also serviceable at temperatures as low as —40 deg. F.

Although these greases are stable at elevated temperatures, the problem of bearing design and construction must be considered. In some instances it will be found advisable to use bearings with larger clearances to compensate for temperature differentials in the bearings. Preliminary tests have shown that the use of bronze ball cages materially lengthens the life of bearings at elevated temperatures. The development of

Data supplied by D. A. Kauppt, Dow-Corning Corp.

silicone greases for journal bearings and extreme pressure lubrication is still in the laboratory stage.

Silicone Electrical Insulation

Silicone varnishes and resins were developed for use with inorganic spacing materials such as Fiberglas, mica, and asbestos in the insulation of electrical equipment. The inorganic skeleton on which these varnishes and resins are built enables them to exclude moisture even after prolonged exposure to elevated temperatures. Used in combination with inorganic materials these materials have provided a new class of electrical insulation, for equipment operating continuously at 175 deg. C. and at temperatures up to 250 deg. C. for limited periods.

Silicone Paints

Resins are available for formulating protective coatings highly resistant to heat, moisture, and outdoor weathering. Light-colored enamels made with these resins and heat-stable pigments have a high degree of chemical resistance, and do not yellow on aging or on exposure to temperatures up to 500 deg. F. Silicone paints pigmented with aluminum powder protect smoke stacks, drying ovens and furnace parts.

Silicone Elastomers

The temperature limitations of natural rubber have long been realized and many attempts have been made to impart to synthetic rubbers the quality of increased thermal resistance. In many instances, these efforts have been successful in raising the safe operating limits of rubber or synthetic rubbers. However, in some cases, elastic materials which remain resilient and do not soften or harden at temperatures above 250 deg. F. are required. In such applications, silicone elastomers can be used. These elastomers resemble, feel and behave like natural and

Table III—Physical Properties of Silastic

Type	Paste		Crepe			
Silastic stocks (Cured for 48 hr. at 390 deg. F.)	120	125	150	160	167	180
Density, at 25 deg. C.	1.7	1.7	1.9	2.1	2.0	1.6
Hardness, Shore A Scale	50-60	40-50	45-55	55-65	55-65	75-85
Tensile Strength, lb. per sq. in.	500	400	400	600	600	700
Elongation, percent	150	200	300	200	110	75
Percent Impact Resilience Bashore Resiliometer	45	52	53	52	54	47
Flex, De Mattis, Method B, Percent of Elongation	50	50	70	50	20	20
Number of Cycles	500,000	500,000	250,000	150,000	80,000	7,000
Percent Water Absorption[1]	1.4	2.8	2.6	0.9	1.3	0.5
Water Absorption[1] Milligrams per sq. in.	20	39	47	17	25	7

[1] After 7 days immersion at room temperature. *Trademark Dow Corning Corp.

Table IV—Electrical Properties of Silastic

Type	120	125	150	160	167	180
Dielectric Constant, 10^6 cycles	7.5	7.5	5.6	9.0	9.8	4.6
Percent Power Factor, 10^3 cycles	0.6	0.6	1.3	0.8	0.4	0.6
Percent Power Factor, 10^6 cycles	0.1	0.1	1.0	2.0	0.1	0.3
Dielectric Strength, Volts per mil	1100	1100	500	500	500	650

Table II—Electrical Properties of DC Fluids
(at 25 deg. C. and 50 percent relative humidity)

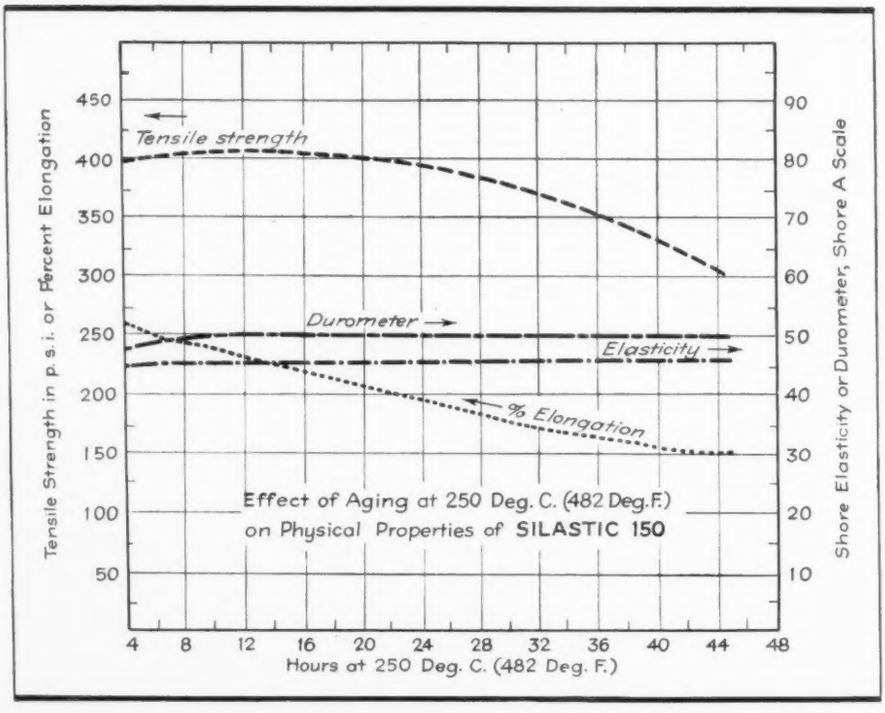
Frequency Cycles/sec.	Dielectric Constant	Power Factor
10^2	2.85	0.0001
10^6	2.83	0.0002
10^7	2.82	0.0002
10^8	2.81	0.0006

Dielectric Strength, volts per mil, 250 to 300
Volume Resistivity, ohms cms., 1×10^{14}

Table I—Physical Properties of Dow Corning Silicone Fluids

Uses of Dow Corning Liquid Silicones	Fluid Type	Viscosity Grade		Viscosity—Temperature Coefficient $(1-\frac{V210°F.}{V100°F.})$	Freezing Point		Boiling Point		Flash Point Minimum °F.	Specific Gravity 25° C./25° C.	Pounds Per Gallon at 25° C.	Expansion Coefficient k x 1000 per °C. 25° C. to 100° C.	Refractive Index at 25° C
		Cstks. at 25° C.	SSU at 100° F.		°C.	°F.	Temperature °C.	Pressure mm.Hg.					
Damping Fluids Hydraulic Fluids Instrument Liquids Liquid Dielectrics Foam Inhibitors Mold Release Agents Waterproof Treatment for Glass and Ceramic Insulators Special Lubricants for Glass, Rubber and Plastics	DC 500	0.65	29	0.31	−68	−90	99.5	760	30	0.761	6.35	1.598	1.3748
		1.0	30	0.37	−86	−123	152	760	100	0.818	6.84	1.451	1.3822
		1.5	31	0.46	−76	−105	192	760	160	0.852	7.11	1.312	1.3872
		2.0	32	0.48	−84	−119	230	760	195	0.871	7.27	1.247	1.3902
		3.0	34	0.51	−70	−94	70-100	0.5	225	0.896	7.48	1.170	1.394
		5.0	40	0.55	−70	−94	120-160	0.5	270	0.918	7.67	1.095	1.397
		10	52	0.57	−67	−88	>200	0.5	350	0.940	7.85	1.035	1.399
		20	78	0.59	−60	−76	>200	0.5	520	0.950	7.93	1.025	1.400
		50	198	0.59	−55	−67	>250	0.5	540	0.955	7.98	1.000	1.402
					A.S.T.M. Four Point*		Volatility on Heating 48 Hours						
					°C.	°F.	at °C.	%					
	DC 200	100	355	0.60	−55	−67	200	<2	600	0.968	8.08	0.969	1.4030
		200	715	0.62	−53	−63	200	<2	615	0.971	8.10	0.968	1.4031
		350	1250	0.62	−50	−58	200	<2	625	0.972	8.11	0.966	1.4032
		500	1750	0.62	−50	−58	200	<2	625	0.972	8.11	0.965	1.4033
		1000	3500	0.62	−50	−58	200	<2	640	0.973	8.12	0.963	1.4035
High Temperature Baths	DC 550	100 to 150	300 to 400	0.75	−48	−54	250	<10	600	1.065	8.90	0.78	1.498
General Lubrication at High Temperature		500	1060	0.89	−12	10	250	<15	520	1.112	9.27	0.71	1.539

*DC 200 Fluids are not recommended for use below about −40° C. (−40° F.).



Comparison of moisture resistance of Class *B* and silicone treated insulation on a.c. generator coils tested at 200 deg. C.

synthetic organic rubbers but retain rubber-like properties at temperatures far above and below the serviceable limits of natural or synthetic organic rubbers. The materials are basically different from most other rubbers in chemical structure. The natural and the synthetic organic elastomers all have the same molecular skeleton consisting of a carbon-to-carbon linked chain with a certain degree of unsaturation. Since these carbon chains are unstable to oxidation and other forms of deterioration, especially at elevated temperatures, organic rubbers either melt or harden at temperatures above 250 deg. F. The silicone elastomers are built on a chain of alternate silicon and oxygen atoms, which imparts heat stability.

Stocks are produced fully compounded and ready for use in the form of crepes and pastes. These crepes are soft, doughy and somewhat elastic materials, for molding, sheeting, friction calendering or extruding. The pastes have the consistency of an ointment or salve and are used in coating and laminating applications. Properly applied and cured, these silicone pastes possess rubber-like properties which are similar to those of the cured crepes.

Only slight changes in its rubber-like properties are noted from —70 deg. F. to over 500 deg. F. Test temperatures from 300 deg. F. to 500 deg. F. are necessary because no appreciable changes in physical properties can be observed even after prolonged exposure to the lower temperatures at which accelerated testing is usually done.

Fabrication of Silicone Rubber

Although almost entirely inorganic, stocks can be handled, in most respects, like compounded rubber. They can be molded, extruded, laminated, or coated by adapting conventional processes and with standard equipment. After the forming operation, stocks are cured by heating in air ovens to complete a reaction similar to vulcanization. This heating develops optimum properties.

Molding

Moldings are made from crepes or pastes. The crepe is easier to handle, however. The material is placed in room temperature molds, press-cured at temperatures between 212 deg. and 300 deg. F. for 3 min., and cooled to at least 100 deg. F. in the press before release of pressure. Heating under pressure produces a reaction similar to vulcanization which gives permanent shape to the molding. Molded pieces are oven cured to develop the various degrees of strength, elasticity, and compression set associated with the hardness of the material used.

Laminating

In general, pastes are recommended for thin moldings, especially those in which only one thickness of fabric is used. A thin coating of paste is spread on both sides of the fabric being laminated. It is not necessary to spread the paste uniformly since even distribution is accomplished by the flow which results when the assembly is compressed.

For thicker laminates the use of sheeted stock between layers of glass or asbestos cloth is recommended. Fabrics can be friction calendered.

Extruding

Silicone rubber in the form of crepes are adapted to extrusion into various shapes and over wire in conventional rubber extruders. The extrusions are precured in a steam autoclave followed by oven curing or are completely oven cured.

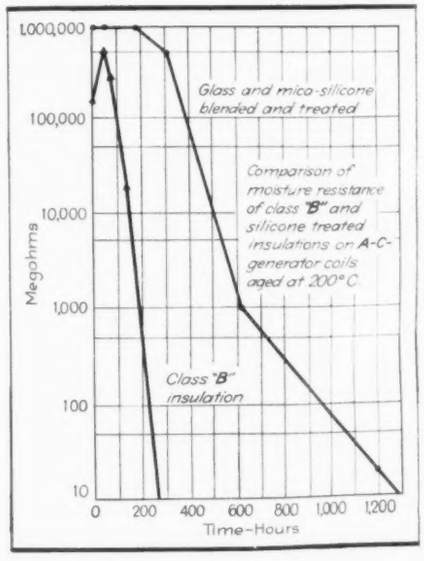
Coating

Coatings using the pastes can be applied to glass, ceramic, or steel surfaces and to glass and asbestos cloth by doctoring, spreading, roller-coating, dipping, or spraying. The pastes are used as received or thinned to the proper consistency with solvents such as petroleum either similar to low boiling naphtha.

Thickness can be built up by applying a succession of thin, uniform layers, each separately cured. Continuous coating operations are not difficult to perform when such variables as rate, thickness, consistency, and curing temperatures are adjusted properly. Fabrics can also be coated with crepe by friction calendering.

Applications

Among the applications already established are: heat resistant gaskets; diaphragms, valve disks and packings; gaskets reinforced with glass or asbestos fabric; coated conveyor belts for services requiring heat resistance; tubing and hose; high temperature rollers, press pads and vibration mountings; embedded transformers; insulated lead wire.



Heat stability of Silastic after aging at 482 deg. F. in a circulating oven for 45 hr. Hardness and elasticity remain essentially constant, tensile strength increases slightly and then decreases, and elongation decreases slowly.

PLASTIC COATED METAL TUBING

Appearance and service advantages of plastic and strength advantages of steel tubing are combined in new stanchions coated by extrusion.

IMPROVEMENTS in extrusion techniques have kept pace with advances in plastic materials. Prior to the war, new formulations and methods were combined to produce extruded trim, rods and tubes. During the war extrusion was extensively used for wire and cable coating. Today, extruded rods, tubes and sheet are being produced as well as special shapes and trim and cable coatings, and in addition the process has been adapted to precise coating of tubing. One of the newest applications is to bus stanchions opening up possibilities in other applications where the advantages of plastics are to be combined with strength properties furnished by the metal.

In a patented method developed by Samuel Moore and Company and Carter Products Company, electrically welded steel tubing is being coated with 1/32 in. of cellulose acetate butyrate, on a continuous process. The plastic not only provides color, but protects against corrosion and is warm to the touch. In addition, because of the strength of the plastic, bending and flaring operations can be performed without damage to the coating. The method, while at present being applied to 0.049 electric welded tubing can be applied to a wide variety of sizes of tubing, or to any metal parts adaptable to continuous processing past an extrusion head.

Coating Process

In the coating process, 14 ft. lengths of tubing are joined with plugs and fed continuously past the extrusion nozzle. The tubing is completely finished as it comes from the cross-header of the machine. No bonding agent is used between the plastic and metal tubing, since the plastic shrinks on during the extruding process. It is claimed that coating thickness can be controlled to within 0.005 in. Coatings to date are 1/32 in. thick, but it is expected that thickness can be as high as 1/4 in. if desired. Bending and flaring operations are done after the tubing is coated. Specially designed machines are used for such operations.

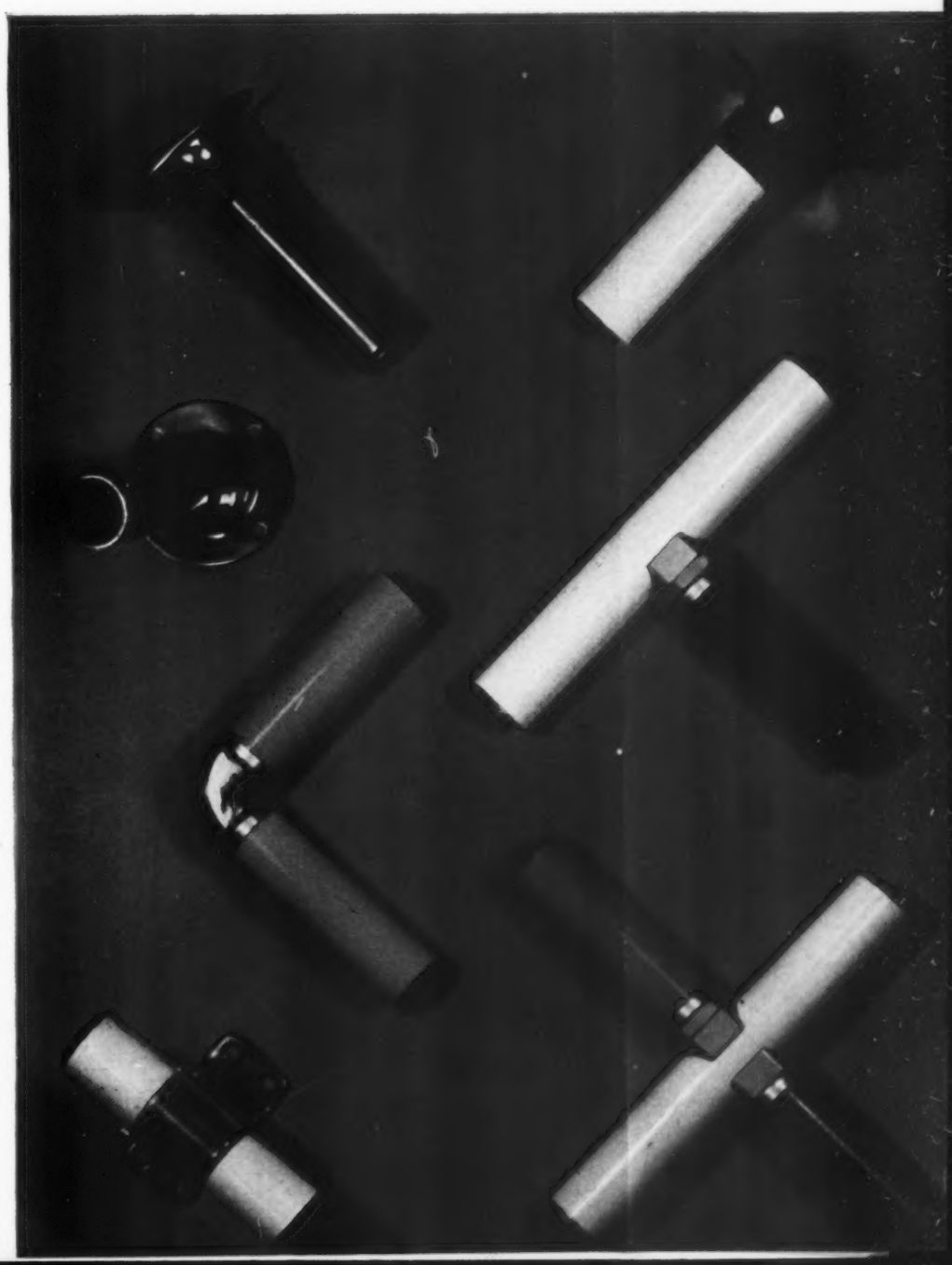
Specific advantages lie in the fact that such stanchions cost less than conventional types. In some cases savings of as much as 25 percent in cost have been realized. The coating is hard enough to be mar-proof, is unaffected by perspiration or salt air, retains elasticity at 30 degrees below zero, and will not soften at temperatures up to 190 deg. F. The stanchions are approximately 20 percent lighter in weight than conventional vencered types. Cleaning is easy and, of course the advantages of color are obtained.

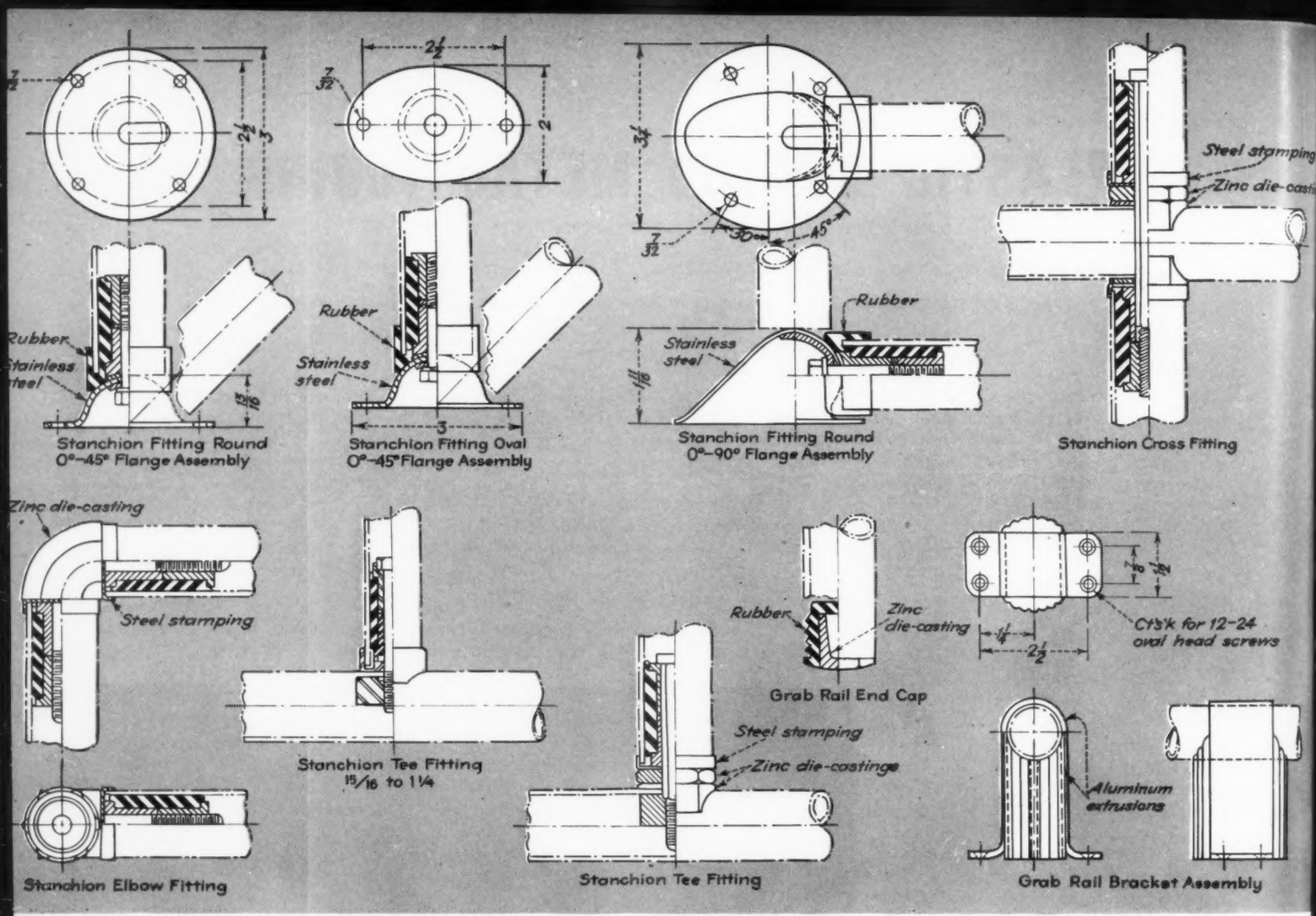
Special Fittings Developed

As an outgrowth of the plastic-coated stanchion development, new fittings, lighter in weight and attractive in appearance, were designed. Conventional design is reversed, that is the fitting is placed in the stanchion. This not only allows a saving in weight, but produces a streamlined effect. And the adaptability of the basic design to permit its use on a number of tubing sizes simplifies installation and inventory problems.

Anchorage is obtained by expansion of a

Cellulose acetate butyrate is extruded over metal tubing to produce bus stanchions in a variety of colors.





Special fittings developed for plastic-coated stanchions. Locking is accomplished by expanded rubber sleeves which bear against the inside wall of the tubing.

Bending operations are performed after tubing is plastic-coated.

rubber bushing as the fitting is screwed or fitted in place. The design is such that the basic fitting can be adapted to various tubing inside diameters by changing the diameter of the rubber bushing. To date, the fittings are fabricated of stainless steel, zinc die-castings, and aluminum extrusions.

POLYVINYL RESINS are now available in latex form for use in coating and impregnating of yarn and wire. The technique utilized is similar to that used when fabric is coated with plastic latex.

A NEW LAMINATING PLASTIC has been developed specifically to provide high surface gloss, flexibility, and stain resistance for decorative laminates.

KNITTED FIBERGLAS CLOTH recently announced is adaptable as filler in low pressure laminating work to provide high strength.

MELAMINE MOLDING COMPOUNDS

New formulations of thermosetting materials offer a wide range of electrical, chemical and physical properties

ALTHOUGH the chemical melamine was synthesized by Leibig more than a century ago, it was not produced commercially ten years ago. Melamine formaldehyde resins have the property of combining readily with various cellulosic and mineral fillers, and by proper combination, a wide range of electrical, chemical and physical properties can be obtained. Four general groupings are now available: alpha cellulose, mineral, chopped cotton and wood-flour-filled melamine molding compounds.

Alpha-Cellulose-Filled Melamine

As with the urea-formaldehyde molding materials, alpha-cellulose-filled melamine compounds have an unlimited range of colors. Other characteristics are resistance to moisture absorption, resistance to chemical attack, staining and discoloration and resistance to abrasion. The compounds also exhibit lack of odor and taste, and heat resistance which will withstand boiling water.

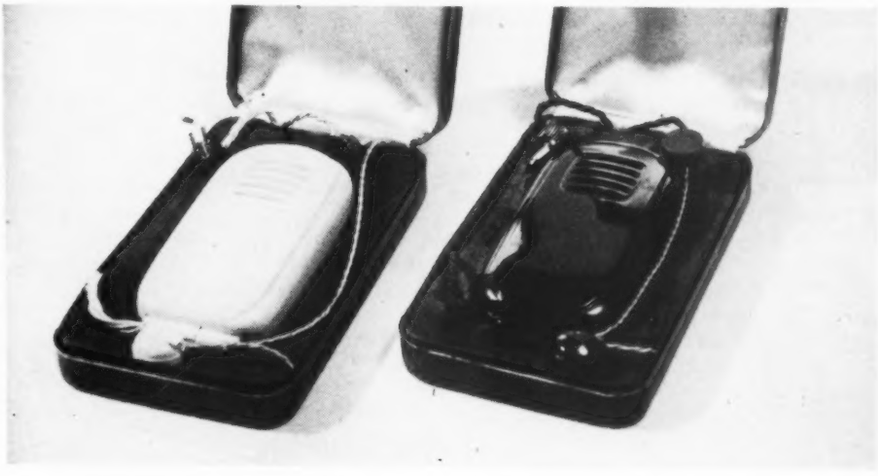
Mineral-Filled Molding Materials

Arc resistance and heat resistance are characteristic of the mineral-filled melamines, available in two types, the first of which was developed as a high heat-resistant material possessing good arc resistance and electrical properties. When formed into moldings the material will withstand up to 400 deg. F.

The other compound involves both a resin and filler adjustment. Some of the heat resistance has been sacrificed, although moldings will perform well in service at temperatures up to 300 deg. F. The primary reason for these resin and filler adjustments is to improve mechanical strength and dimensional stability. This particular compound has arc resistance superior to other thermosetting plastics, molds well around metal inserts and has excellent electrical properties.

Both materials are available in a wide range of plasticities ranging from soft flow, satisfactory for under-pressured molds and intricate transfer operations, to a hard flow which may be used for rapid production of small or thin-sectional parts by the compression molding technique. It is interesting to note that this extremely wide flow range has little or no effect on the physical, mechanical, electrical or chemical properties of the molded article.

This characteristic is particularly true of shrinkage. Throughout the flow range the difference is so small that it is seldom neces-



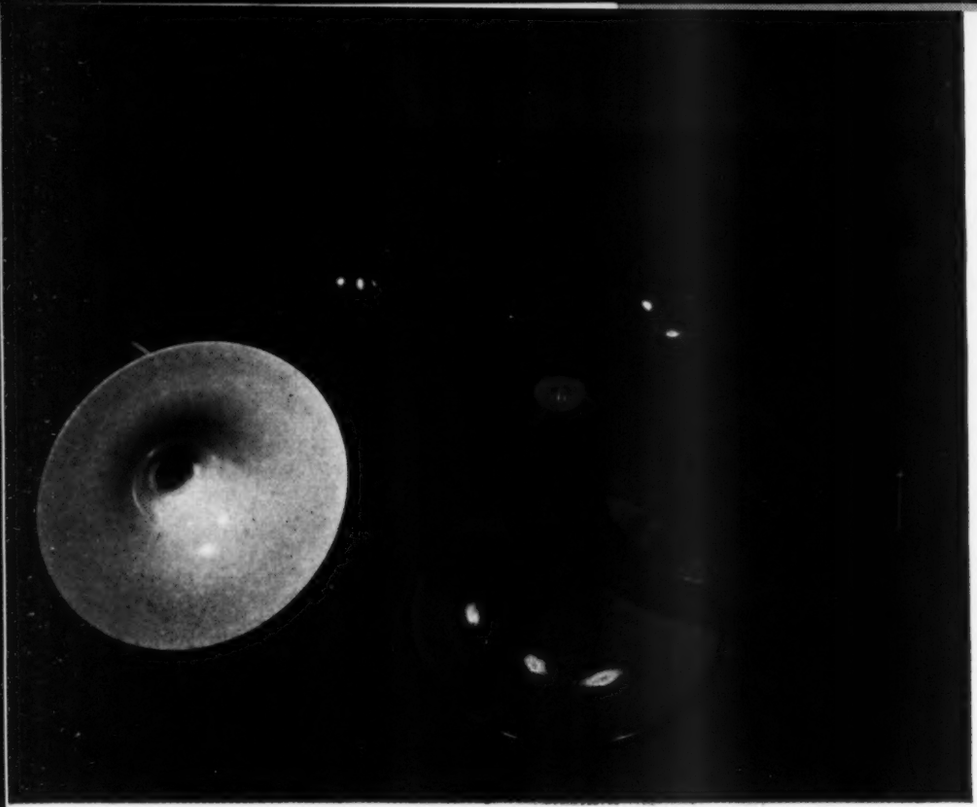
Abrasion and perspiration resistance combine with attractiveness of appearance in this hearing device case molded of melamine

Based on material supplied by P. W. Fuller, American Cyanamid Co.

Typical Properties, Melamine Molding Compounds

Characteristics	A Generally equivalent to urea materials, with better resistance to water, heat.	B For electrical application satisfactory for transfer molding.	C A high heat resistant material, not recommended for large inserts	D Low-gravity wood-filled for electrical application	E Chopped cotton impact material, high flexural strength	F Chopped cotto filled phenol-mod fied material. Hig flexural strength.
SPECIFIC GRAVITY (molded) gms per c.c.	1.49	1.7	1.98	1.45	1.4	1.4
TENSILE, lb. per sq. in.	6,600–8,300	5,400–6,900	5,300–7,000	5,750–6,500	5,500–7,500	———
FLEXURAL, lb. per sq. in.	13,000–15,000	8,360–10,300	7,700–11,700	10,000–13,000	12,000–15,500	12,000–15,500
IMPACT, 1,200 ft. lb.	0.23–0.28	0.28–0.38	0.27–0.38	0.29–0.36	0.35–0.82	1.0–1.5
HEAT DISTORTION POINT, deg. C.	206	130	130	———	———	———
COEFF. EXPANSION per deg. C.	23×10^{-6} (−45 deg. C.)	22×10^{-6} (−40 deg. C.)	17×10^{-6} (−40 deg. C.)	———	———	———
	44×10^{-6} (15 deg. C.) 57×10^{-6} (75 deg. C.)	37×10^{-6} (25 deg. C.) 43×10^{-6} (60 deg. C.)	25×10^{-6} (25 deg. C.) 30×10^{-6} (60 deg. C.)	——— ———	——— ———	——— ———
WATER ABSORPTION percent 24 hr. at 25 deg. C.	0.7	0.13	0.02–0.18	0.019–0.040	0.010–0.20	0.8–1.3
ARC RESISTANCE sec.	120–130	124–140	151–188	95–130	70–128	———
DIELECTRIC STRENGTH volts per mil Room Temp. 100 deg. C	320–360 220–300	470–570 440–540	490–500 360–510	350–380 270–320	190–350 110–135	——— ———
POWER FACTOR 60 cycles 10⁶ cycles	0.022–0.051 0.028–0.029	0.10 0.038	0.08–0.15 0.028	0.03–0.08 ———	——— ———	——— ———
DIELECTRIC CONSTANT 60 cycles 10⁶ cycles	7.5–8.3 6.7–7.3	7.7 5.65	7.4–10.0 5.8	6.4–8.5 ———	——— ———	——— ———

[1]Data based on A.S.T.M. test procedures, furnished by American Cyanamid Company.



Color possibilities with new Melmac materials are illustrated in these compression-molded washing machine agitators.

sary for the molder to concern himself about shrinkage versus flow during the design of the mold.

The first volume application for mineral-filled melamine resulted from the acute need for an improved dielectric and arc-resistant material for aircraft ignition parts, such as large distributor heads and other ignition moldings, formerly of hard rubber. Finished ignition parts have good electrical properties and the molding compound performs well in its role of high tension insulator, as a dielectric and as a resistant surface to electrical flash-over and tracking. Surface breakdown caused by arc-tracking through a moist deposit of foreign matter seldom results, since the first few surges of current usually dissipate the dampness, and the non-conducting plastic surface functions normally as an insulating material. Ignition systems on most combat aircraft were equipped with this material. The material responded well to standards methods of molding. The rapid advancement in the science of prewarming from the hot plate to the high frequency machine has done much to improve the moldability of mineral filled materials.

Several manufacturers of farm equipment have adopted these materials for tractor ignition systems. New uses include automotive ignition parts, as well as in the electrical field for such circuit breakers, terminal blocks, and industrial controls.

Chopped Cotton Filled Melamine

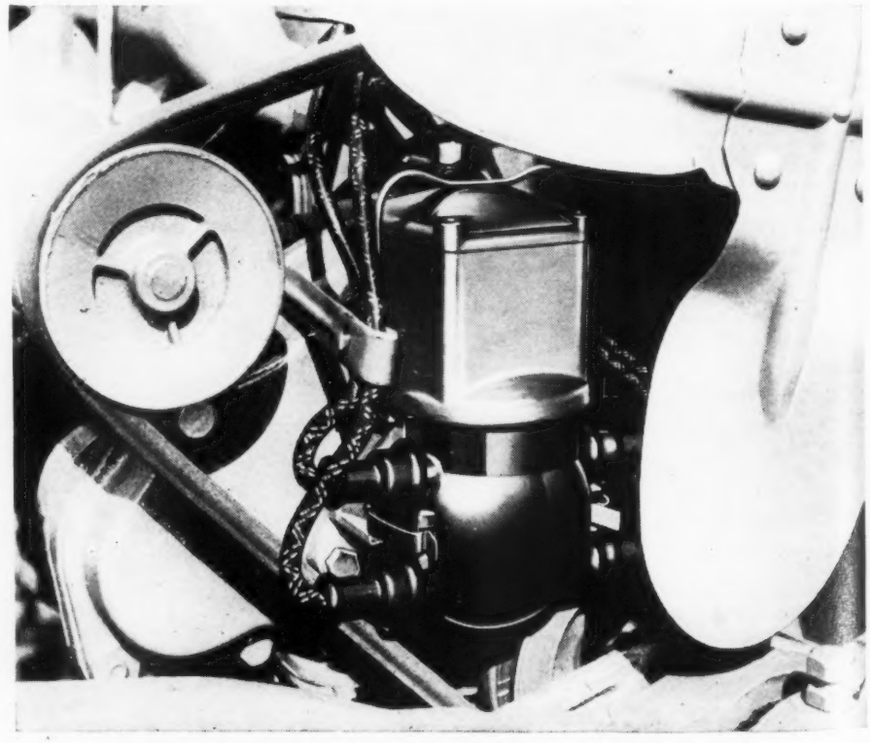
Chopped-cotton-fabric-filled material was developed for industrial applications where resistance to shock on the part of the finished product is desired. When this property must be combined with other physical and chemical properties, this material is effective. A special compound was developed for the Army, consisting of a melamine resin, modified with a small amount of phenolic resin, for additional strength.

Typical applications include electric control mechanisms on heavy-duty mining machinery where an insulating material which combines resistance to shock is desired, washing machine agitators, vacuum cleaner housings, and as plastic collars on brush stud holders for heavy-duty electric motors. In this application, the plastic joins two metal parts and at the same time provides electrical insulation. It has also been used for large circuit breakers and heavy duty handsets.

Originally the material was supplied in two colors, black and opaque mottled white. Experimentation with various grades of cotton cloth, with bleaches and dyes brought forth the first shock resistant thermosetting molding compound available in color. The range of colors in this new material include white, blue, red, green, brown and black.

Wood-Flour-Filled Compounds

One of the versatile melamine molding compounds is a combination of the resin with a wood-flour filler. This material combines nearly all of the well known electrical properties of the mineral-filled products with lower specific gravity and excellent molding characteristics. Suitable for either compression or transfer molding techniques, wood-flour filled melamine is satisfactory for general applications in the electrical insulation field. This compound is used for such items as electric stove switch blocks, circuit breakers, connector plugs, electric motor parts and other industrial and electrical molded parts where arc resistance and heat resistance are required.



Asbestos-filled Melmac, a wartime development, finds peacetime use in the distributor head of the Ferguson tractor motor.

POLYETHYLENE

Developed for wartime electronic applications, this new thermoplastic combines excellent electrical properties with insensitivity to moisture.

POLYETHYLENE is a thermoplastic, of microcrystalline structure and hence having a well-defined softening temperature. The material now commercially available softens at 108-112 deg. C. By reason of its crystalline structure polyethylene is translucent rather than transparent.

Theoretically, a polymer of ethylene is the simplest in chemical structure of all of the synthetic resins, and completely non-polar. As manufactured, polyethylene deviates little from this theoretical perfection; it is almost completely non-polar and has an extremely low power factor at all frequencies.

Other outstanding properties are high resistance to water and to the passage of water vapor, resistance to most chemicals and solvents at ordinary temperatures, and retention of good flexibility and toughness at very low temperature. Flexibility and toughness are inherent properties. It is not necessary to add plasticizer, even to protect these properties at low temperature. Thus polyethylene plastics are free from the disadvantages sometimes contributed by the use of plasticizers: that the resulting plastic has odor or taste, that it may contaminate adjacent material, or that it may suffer change in properties through loss of plasticizer by evaporation or extraction.

For extrusion as wire-covering, as sheeting or as rods, tubes, and the like, equipment and general technique are not essentially different from those employed with other thermoplastics. The unusual large coefficient of thermal expansion, however, makes it necessary that extruded material of thick section be cooled slowly in order to avoid shrinkage voids.

In compression molding, a mold of flash type is likely to be unsatisfactory because thermal shrinkage occurring after the mold is closed will cause voids in the piece. A positive or at least a semi-positive mold should be used, and full pressure should be applied only after cooling has been started. In injection molding, maintenance of pressure on the piece as it cools must be assured by providing generous channels from the nozzle to the mold cavity and by avoiding too rapid setting of the material.

Thin sheets can be bonded together by application of the heat of small flame or of a hot iron, but cannot be bonded by the so-called electronic sewing machine because the power factor of polyethylene is so low that

Data supplied by A. F. Randolph, E. I. du Pont de Nemours & Co., Inc.

Typical Properties of Polyethylene

(Block Process Sheeting 15,000–25,000 Approximate Molecular Weight)

Properties	Average Test Values	Test Method
Tensile strength lb. per sq. in.	.....	ASTM D412-41
−70 deg. F (0.075 in.)	7,600	(Die "C")
77 deg. F (0.075 in.)	1,900	
170 deg. F (0.075 in.)	1,000	
Elongation percent	.....	ASTM D412-41
−70 deg. F	50	(Die "C")
77 deg. F	600	
170 deg. F	575	
Modulus of elasticity 77 deg. F lb. per sq. in.	13,000	
Stiffness lb. per sq. in.	.....	ASTM D747-43T
−40 deg. F	130,000	
77 deg. F	13,000	
160 deg. F	5,000	
Impact strength, Izod, ft.-lb./in.	.....	ASTM D256-43T
−70 deg. F	.044	
77 deg. F, 170 deg. F	Did not break in 4 ft.-lb. machine	
Rockwell number (average)	R36	ASTM D229-43
Durometer indentation	A98, D45	ASTM D676-42T
Tear-resistance lb./in. of thickness (0.075 in.)	570	ASTM D624-41T
Shear strength lb. per sq. in. (0.125 in.)	1,500	Johnson shear jig
Dielectric strength short time v/m (0.125 in.)	460	ASTM D149-40T
Volume resistivity ohm-cm	$> 10^{13}$	ASTM D257-38
Dielectric constant	.....	ASTM D150-42T
60 cycles	2.3	
10^3 cycles	2.3	
10^6 cycles	2.3	
10^8 cycles	2.3	
Power factor percent	.....	ASTM D150-42T
60 cycles	<0.05	
10^3 cycles	<0.05	
10^6 cycles	<0.05	
10^8 cycles	<0.05	
Deformation under load percent	.....	ASTM D621B-44T
122 deg. F	106	
158 deg. F	0.8	
Heat distortion temperature	.....	ASTM D648(b)-44T
Low load deg. F	107	
	0.55	
	9×10^{-5}	ASTM D696-42T
Specific gravity (weighed in alcohol)	2.15	Cenco Fitch Apparatus
Index of refraction N_D 25 deg. C	0.92	ASTM D792-44T
Water absorption percent	1.51	ASTM D542-42
Flammability in/min. (0.125 in.)	0.00	ASTM D570-42
in^2/min. (0.040 in.)	1.1	ASTM D635-41T
	4.0	ASTM D568-43

Typical polyethylene products—tray, jar tops, sheeting, collapsible tube, wire insulation

it is not adequately heated by this means. Massive pieces of polyethylene can be neatly and strongly sealed together by application of a small flame.

To apply a coating by flame-spraying, comminuted polyethylene of proper fineness is fed continuously through a pistol into a flame fed with a fuel gas and air or oxygen in adjusted proportions. On horizontal surfaces, a coating may be produced by sprinkling a uniform layer of comminuted polyethylene and fusing it by baking. Coating by dipping in molten polyethylene is feasible, but not with current commercial material, which gives too viscous a melt.

Since there is no practicable solvent for polyethylene at room temperature, coating by the aid of solvent necessitates the use of a hot solution, above the temperature at which the plastic will precipitate from the solvent. Then, the coated article is kept hot until the solvent has been evaporated.

NYLON

High-strength, temperature-resistant industrial parts are now molded of nylon.

NYLON MOLDING POWDERS are thermoplastics, and several behave in much the same manner as the older thermoplastics, such as cellulose acetate, and can be molded in substantially the same way. It must be remembered that nylon is the name of not one single substance but of a group of chemically similar synthetic resins, and that the potentialities of many of them have not been fully explored.

Nylon FM-1, however, differs strikingly from the conventional thermoplastics in having a relatively high flow temperture and in softening very sharply at that temperature. It is almost correct to say that FM-1 has a melting point, for although when it is gradually heated it shows a gradual increase in flexibility, the softening is not pronounced until the actual flow temperature is reached. The quite abruptly the solid becomes a viscous liquid. The behavior of FM-1 nylon makes modifications of ordinry processes of molding necessary. The several nylon molding powders now on the market require temperatures ranging from 150 to 270 deg. C. (300 to 520 deg. F.) for molding.

The fluidity of molten FM-1 is advantageous in facilitating the molding of pieces of complicated shapes and of thin section, and also in enabling molding to be done effectively under pressures considerably lower than those required by those thermoplastics which, instead of becoming liquid, are merely made plastic by heat.

The relatively high cost of nylon molding powders excludes them from indiscriminate use, but is well justified in uses where the inherent good properties of the material are desirable. The outstanding properties which determine the fields of use of nylon molding compounds are their unusual toughness and their ability to serve undistorted at relatively high temperature.

The ability of nylon to be molded in very thin sections, and its toughness and strength in thin sections, are well exemplified in tiny injection-molded coilforms used in aviators' radio headphones, altimeters, and sound-powered telephones. In the smallest of these, the wall thickness is only 0.008 inch.

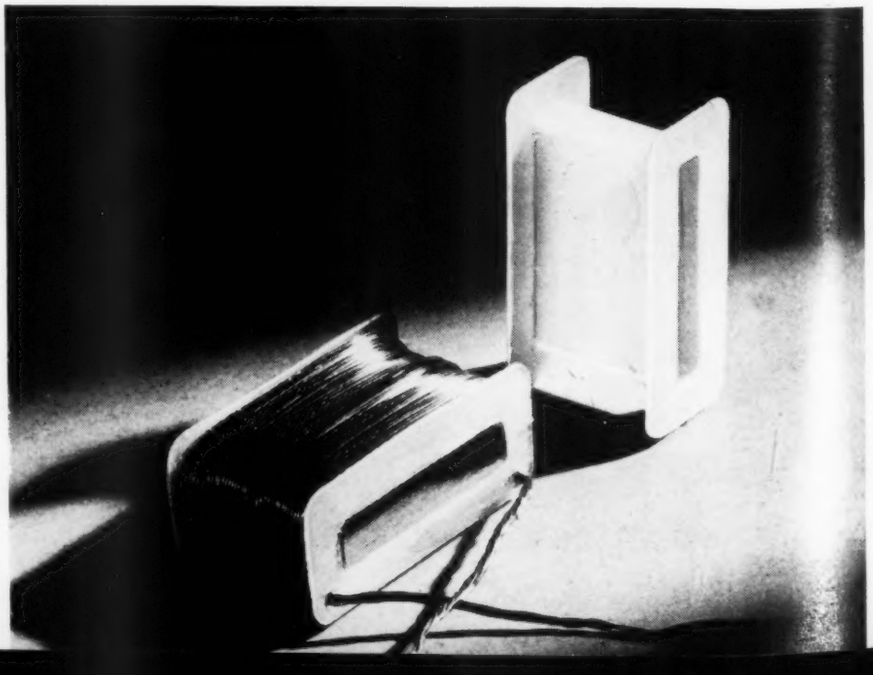
Advantage has been taken of the toughness, abrasion-resistance and flexibility of molded nylon in redesigning an air-valve used in torpedoes, superseding the former metal-to-metal seat with one of metal-to-nylon, which can be closed tight even over particles of grit. The nylon piece sets accurately in place without need of any lapping or finishing.

During the war, a large part of the available supply of nylon molding compound was devoted to the sheathing of insulated wire.

Typical Properties Nylon, type FM-1

Specific gravity		1.14
Tensile strength, lb. per sq. in.		9,500
Modulus of elasticity in tension, lb. per sq. in.		4.5×10^5
Flexural strength, lb. per sq. in.		15,000
Hardness, Rockwell		L95–L100
Coefficient of linear expansion, per deg. C.		9×10^{-5}
Softening temperature, deg. F.		450
Volume resistivity, ohm- m		50% R.H. 10^{13}
Dielect ic constant, 60 cycles,	0% R. H.	3.7
	50% R. H.	4.1
Power Factor, % 60 cycles,		1.4
10^3 cycles,		2.0
10^6 cycles,		4.0
Water absorption, percent by wt., 24 hr., 100% R. H.		1.5
Burning rate		low, self-extinguishing
Effect of age		none
Chemical resistance		Soluble in cresol phenol, formic acid, and concentrated mineral acids. Unaffected by alkalis and weak acids decomposed by oxidizing acids.

Coil forms were among the first applications for molded nylon.



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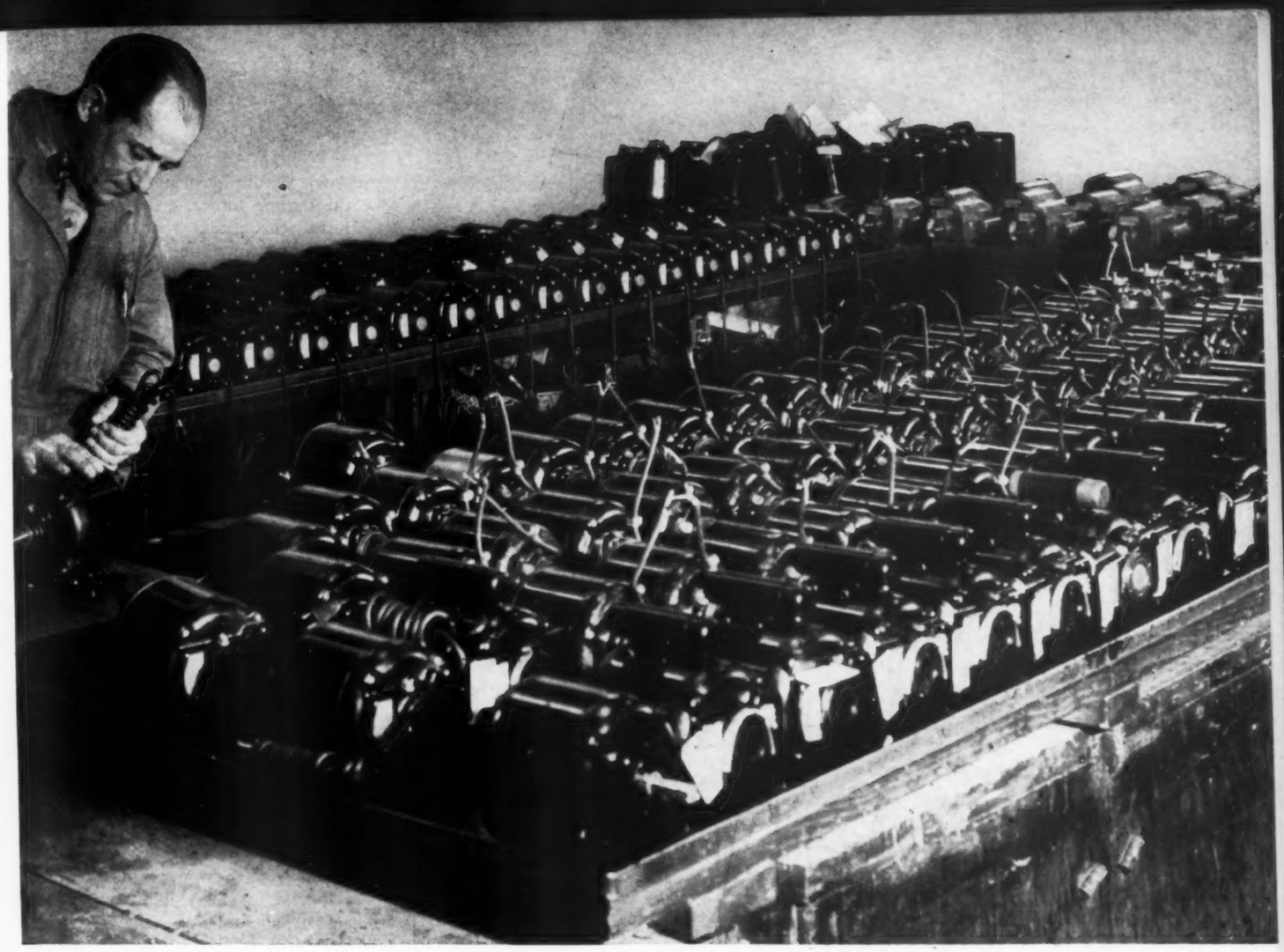

Standard Small Motors Can Fit Most Design Needs—I

CYRIL G. VEINOTT
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The first of two articles interpreting the electrical performance of standard fractional horsepower motors. The operation, characteristics and typical applications of split-phase, capacitor-start, and single-value capacitor types of motors are discussed.

MANY TYPES of standard a.c. and d.c. small motors are available, each having its own distinguishing starting and running characteristic. The wide range of characteristics makes it possible for product designers to select the type of motor that is especially suited for the load characteristics of the machine that is to be driven.

Although the performance of any of the standard type motors can be modified at extra cost, the range of operating characteristics obtainable in the standard types of motors is great enough to usually enable the selection of a standard type motor to meet the load requirements. Therefore this article will confine itself to an explanation and comparison of the operating characteristics of various types of standard single-phase a.c. and d.c. fractional horsepower motors.

Alternating current fractional horsepower motors are generally of the induction type, using a squirrel-cage rotor. Because single-phase induction motors are not inherently self starting, they are commonly classified by their starting methods. These classifications are: Split-phase, capacitor-start, single-value capacitor, and shaded-pole.

SPLIT-PHASE MOTORS. Split-phase induction motors, as shown in Fig. 1, have a main

and an auxiliary stator winding which are displaced 90 electrical deg. in space and a starting switch.

When power is supplied to the motor, current flows through both the main and the auxiliary winding thereby producing a torque action which starts the rotor turning. When the rotor speed reaches 70 to 80 percent of its synchronous speed, the centrifugal starting switch opens the auxiliary winding circuit and the motor continues to run on only the main winding.

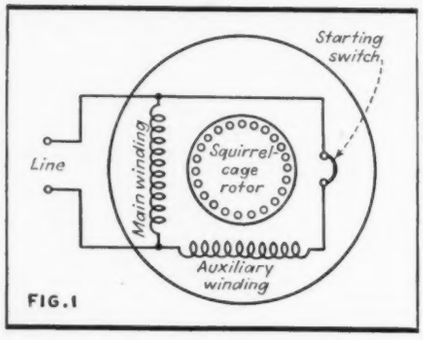


FIG. 1

Fig. 1—Schematic diagram of a split-phase motor showing the squirrel cage rotor; the auxiliary, or starting winding; the main, or running, winding; and the centrifugal starting switch.

Fig. 2—A vector diagram of the locked-rotor currents in a general-purpose 1/6-hp. 110 volt, 60 cycle, 1,725 r.p.m. split-phase motor. Starting torque is developed because of the 24.3 deg. difference in phase between the current in the main winding and that in the auxiliary winding.

How starting torque is developed is explained by the vector diagram of a typical 1/6 hp., 110 volt, 60 cycle, general-purpose split-phase motor shown in Fig. 2. The locked-rotor current in the main winding is approximately 11 amp., and lags behind the applied voltage 40.6 deg. because of the reactance of the winding.

The locked motor current in the auxiliary winding is about 9 amp. Because the auxiliary winding has fewer turns and is of smaller diameter than the main winding, its lower reactance and greater resistance causes the current to lag the voltage by only about 16 deg. It is the difference in phase between the current flowing in the main and auxiliary windings, in this example 24.3 deg., that causes the motor to start. As shown in Fig. 3, the 24 deg. displacement results in a starting torque of approximately 150 percent of full-load torque. Up to the maximum 90 deg. relationship in a two-phase motor, the larger the angle of displacement the greater will be the starting torque.

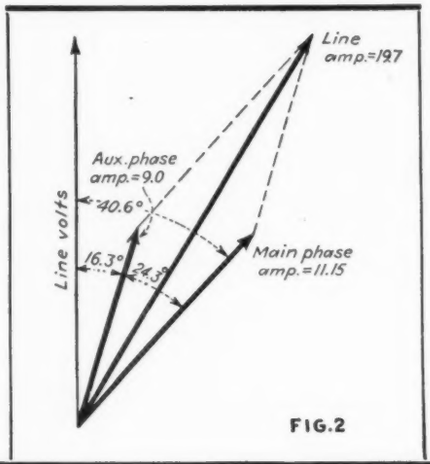


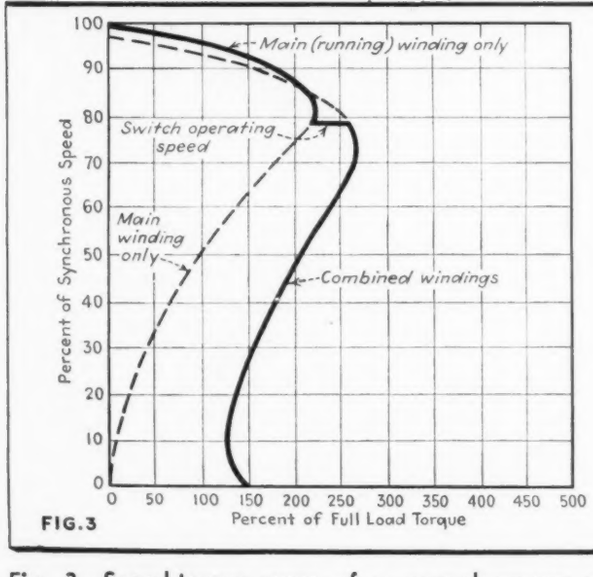
FIG. 2

During the period that the speed of the motor is increasing from zero to a speed at which the starting switch opens, the speed-torque characteristic of the motor is that developed by current flowing through both the main and the auxiliary winding. As shown in Fig. 3, when the switch opens its contacts the torque drops back to that produced by the main winding alone.

The starting switch is usually centrifugally operated. However, in hermetically sealed refrigerator motors, a magnetic relay is often used to avoid having a switch operating inside the refrigerant. A starting switch, or its equivalent, is necessary to prevent the starting winding from burning out and to avoid the excessive losses and low efficiency that would result if the starting winding remained in circuit.

There are two basic types of split-phase motors: General-purpose, formerly called long-hour; and high-torque, or short-hour. The speed-torque characteristic of a typical general-purpose motor is shown in Fig. 3. General-purpose motors are usually built in a wide variety of ratings up to 1/3 hp. They are used principally where moderate starting and break-down torques are sufficient and are suitable for use on lighting circuits because of their low lock-rotor current. Typical applications include oil burners, fans, blowers, hermetically sealed refrigerator units, and hot water circulating pumps.

The speed-torque characteristic for a typical high-torque motor is shown in Fig. 4. High-torque motors are built only in


Main (running) winding only
Switch operating speed
Main winding only
Combined windings
Percent of Synchronous Speed
Percent of Full Load Torque
0 10 20 30 40 50 60 70 80 90 100
0 50 100 150 200 250 300 350 400 450 500
FIG. 3

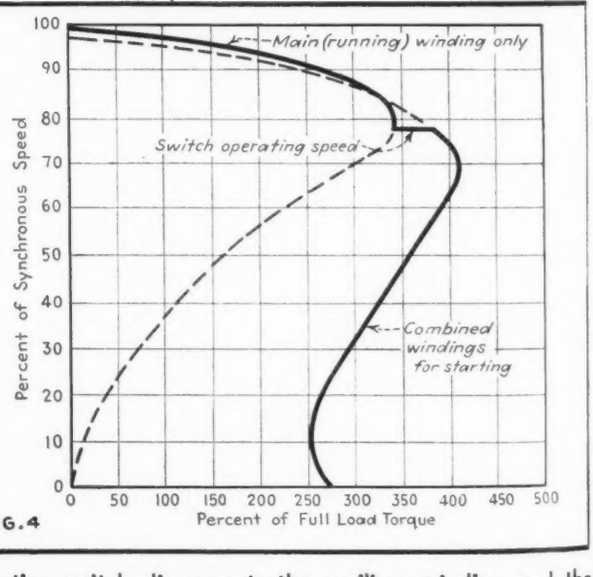

Main (running) winding only
Switch operating speed
Combined windings for starting
Percent of Synchronous Speed
Percent of Full Load Torque
0 10 20 30 40 50 60 70 80 90 100
0 50 100 150 200 250 300 350 400 450 500
FIG. 4

Fig. 3—Speed-torque curve of a general-purpose split-phase motor. During the starting period, the motor operates on the combined characteristic of the auxiliary winding and the main winding. When the motor reaches about 78 percent synchronous speed, the centrifugally operated starting switch disconnects the auxiliary winding and the motor continues to operate on only the main running winding. Fig. 4—The speed-torque curve of short-hour split-phase motor is similar to that of the general-purpose split-phase motor except that the torques are much greater.

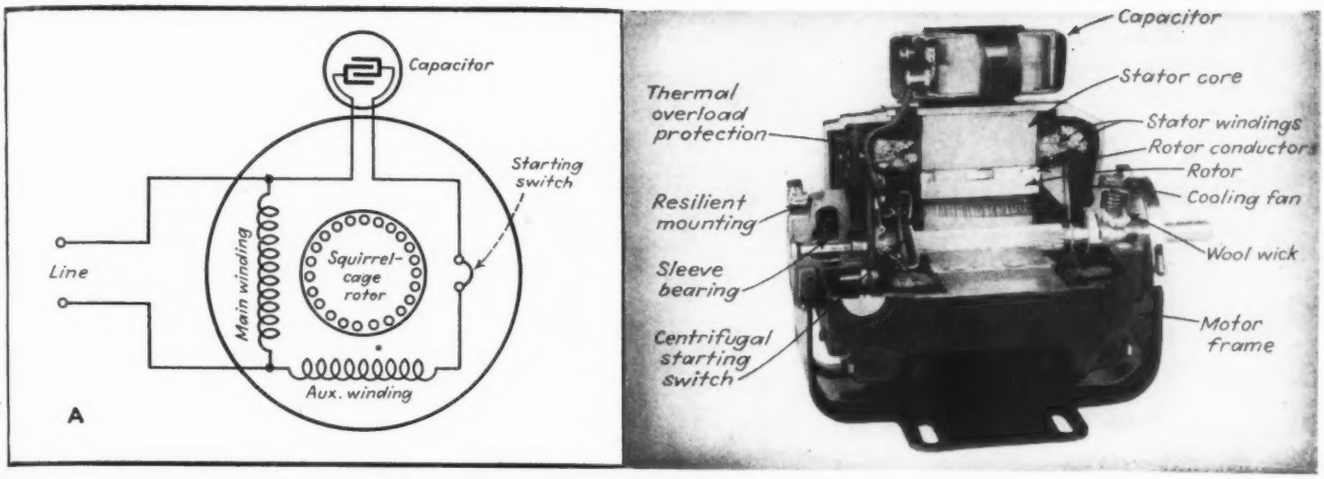


Fig. 5—The capacitor-start motor. (A) The schematic diagramof the capacitor-start motor. The circuit elements are the same as for the split-phase motor except that a capacitor is added in the starting circuit to obtain better starting performance. (B) Cutaway view of capacitor-start motor.

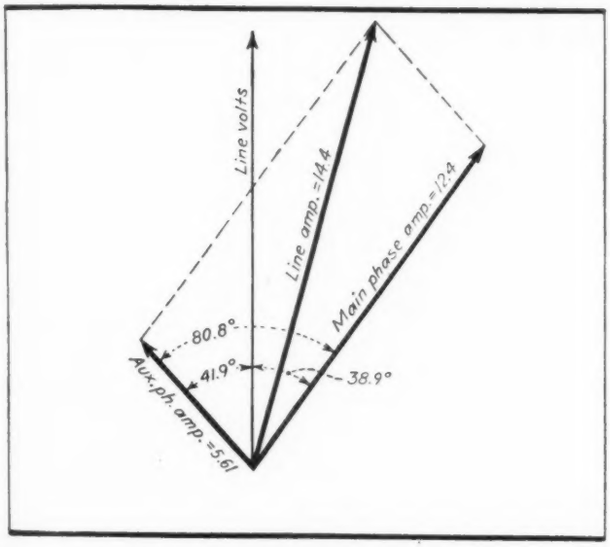


Fig. 6—A vector diagram of the locked-rotor currents in a general-purpose 1/6 hp. 4 pole, 60 cycle, 110 volt, 1,725 r.p.m. capacitor-start motor. The capacitor causes the 80.8 deg. phase angle between the current in the two windings. Compared to Fig. 2, this results in more than double the starting torque but with only two-thirds the line current.

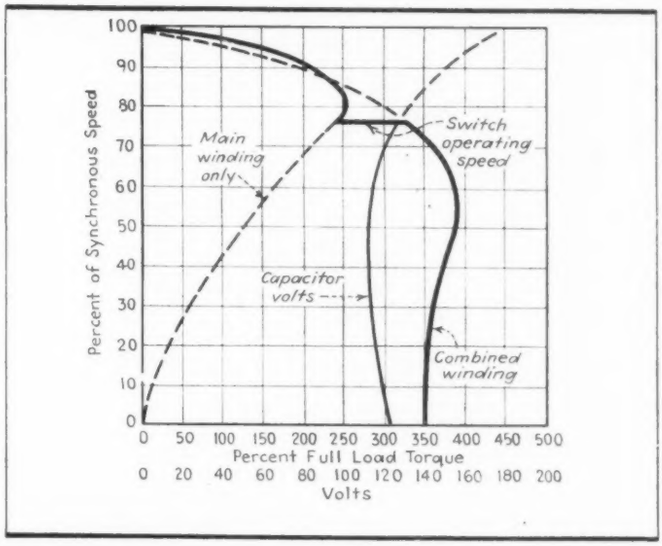


Fig. 7—Speed-torque curve of a capacitor-start motor shows that about 350 percent full-load torque is produced at starting. This is more than double the starting torque of the comparable general-purpose split-phase motor. As the speed increases above 70 percent, voltage across the capacitor would continue to increase as shown if the starting switch did not disconnect the starting circuit.

limited speed ratings and are primarily designed for continuous and intermittent-duty applications where operation is infrequent, and where first cost is more important than operating cost. Their principal application is for washing machines, but they are also used for ironers, sump pumps, and similar equipment that requires high starting torque. Because of their high locked-rotor current, the high-torque motor may cause light flicker on under-wired or overloaded lighting circuits.

Two-speed split-phase motors generally have two main windings, with either one or two starting windings. Such motors are used where two-speed operation is desirable and where moderate starting and running torques are sufficient. Typical uses include belted furnace blowers, attic ventilating fans and similar applications.

CAPACITOR-START MOTORS. The capacitor start motor is the heavy-duty general-purpose constant-speed single-phase motor. Essential elements of a capacitor-start motor are shown in Fig. 5. Compared to the corresponding diagram for a split-phase motor shown in Fig. 1, the capacitor-start motor appears to be a split-phase motor with the insertion of a capacitor in the starting winding circuit. Addition of a capacitor to a split-phase motor will not convert it into a satisfactory capacitor-start motor; nor will omitting the capacitor from a capacitor-start motor provide a split-phase motor.

To provide the best capacitor starting conditions, more turns, and therefore more wire, are usually used in the starting winding of a capacitor-start motor. As shown for a typical 1/6 hp. capacitor-start motor in Fig. 6, the capacitor creates a phase displacement of nearly 90 deg. between the current in the auxiliary winding and that in the main winding, thus approximating the locked-rotor conditions of a two-phase motor. With the same line current, much more starting torque is obtained in a capacitor-start than in a split-phase motor primarily because of the greater phase displacement between these currents.

The starting torque produced is primar-

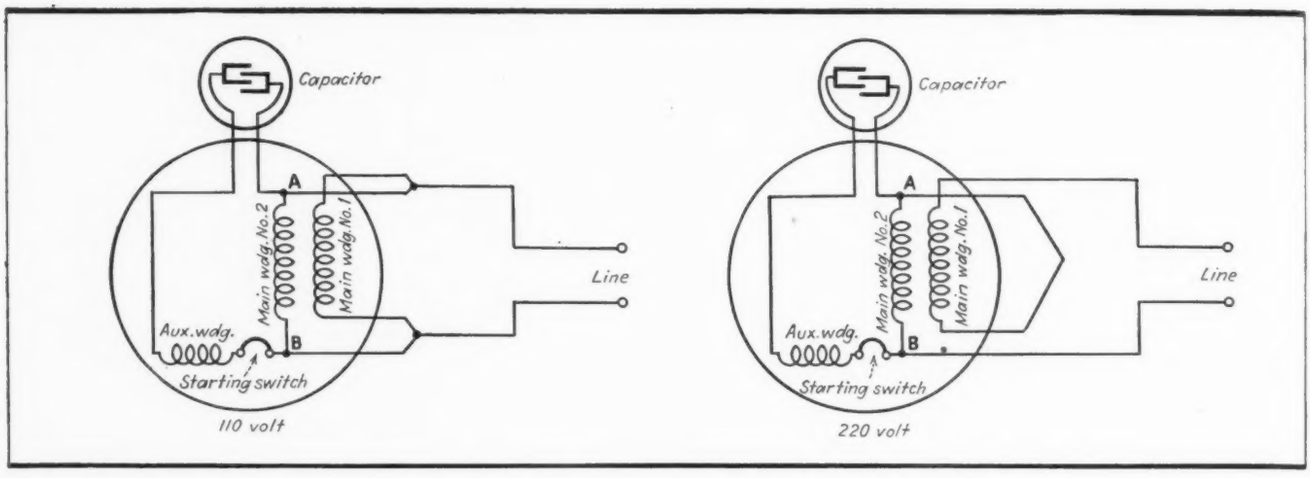


Fig. 8—Wiring and line connection diagrams of a dual-voltage capacitor-start motor. The two sections of the main winding can be connected in parallel or series for 115 or 230 volt service. The auxiliary phase is connected in parallel with one section of the main winding *AB*. When the main winding is connected in series for 230 volt operation, it acts as an autotransformer and impresses only 115 volts across the auxiliary starting phase.

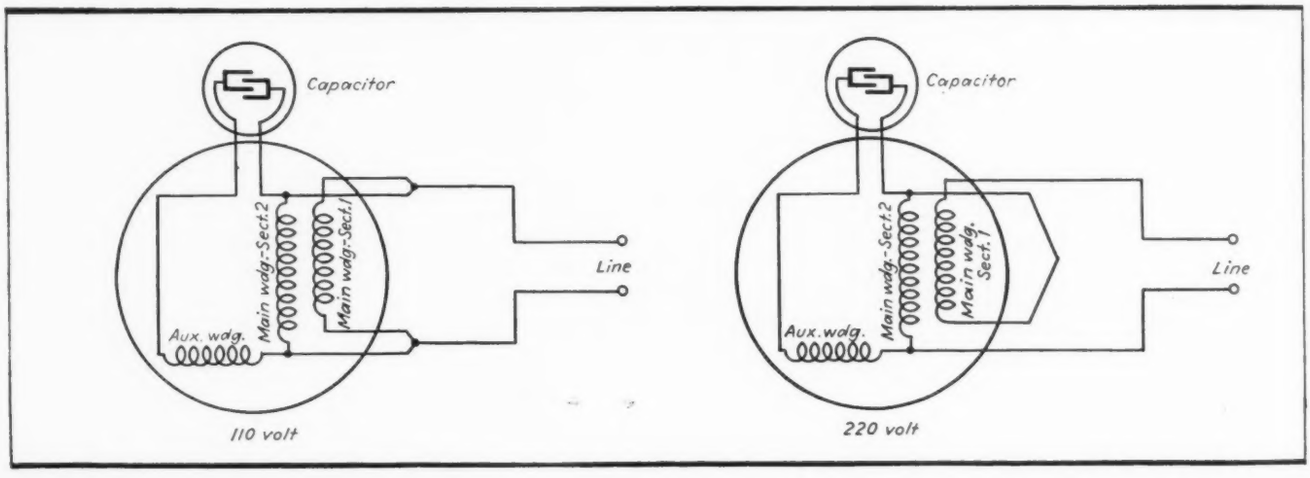


Fig. 9—Wiring and line connection diagrams of a single-value, dual-voltage capacitor motor with series-parallel main winding. No starting switch is used; the auxiliary winding and capacitor are always in the motor circuit.

ily a function of the angle of phase displacement. It is proportional to the sine of that angle and to the magnitude of the product of the currents in the main and auxiliary windings; in other words, it is proportional to the area of the parallelogram of vectors. The line current will increase more rapidly in Fig. 2 than in Fig. 6, for the same increase in current in either the main or auxiliary winding.

The great improvement in starting torque is shown on the speed-torque curve of Fig. 7. A 1/6 hp. capacitor-start motor, compared to a 1/6 hp. split-phase motor, has much more starting torque, and appreciably lower locked-rotor current. A starting switch is used for the same reasons as in a split-phase motor and also to prevent an over voltage from building up across the capacitor. As shown in Fig. 7, after about 70 percent speed, the voltage across the capacitor increases with the speed.

Two-speed capacitor-start motors use two main windings. They usually are 1/3 to 3/4 hp. and are applied in the same general field as the two-speed split-phase motors.

For ratings above 1/4 hp. capacitor-start motors generally have dual voltage windings as shown schematically in Fig. 8. The main winding has two sections that can be connected either in series or in parallel, with the starting circuit connected in parallel with one of the two sections. The starting circuit includes the auxiliary starting winding, starting switch, and capacitor. On the high-voltage or series connection, the main winding serves not only as a main winding but also as an autotransformer with a two-to-one ratio, stepping down the voltage for the starting phase. Special arrangement of the windings is employed so that the main winding will function effectively as an autotransformer. With this arrangement, only four external leads need to be brought out to the usual terminal board or built-in conduit box.

Capacitor-start motors are used for general-purpose applications requiring high starting torque, low starting current, quietness, and high efficiency. Typical applications include compressors, pumps, stokers, machine tools, hoists, refrigerators and air-conditioning equipment.

SINGLE-VALUE (PERMANENT-SPLIT) CAPACITOR MOTORS. Single-value capacitor motors have a main winding and an auxiliary winding displaced 90 deg. apart in space. However, the single-value capacitor motor has a capacitor in series with the auxiliary winding, and this capacitor is always in circuit for both starting and running conditions. These motors are generally characterized by low starting torque and should not be confused with the capacitor-start motors, that have an extremely high starting torque, or the intermittent-duty single-value capacitor motors that have high starting torque. In Fig. 9, connection dia-

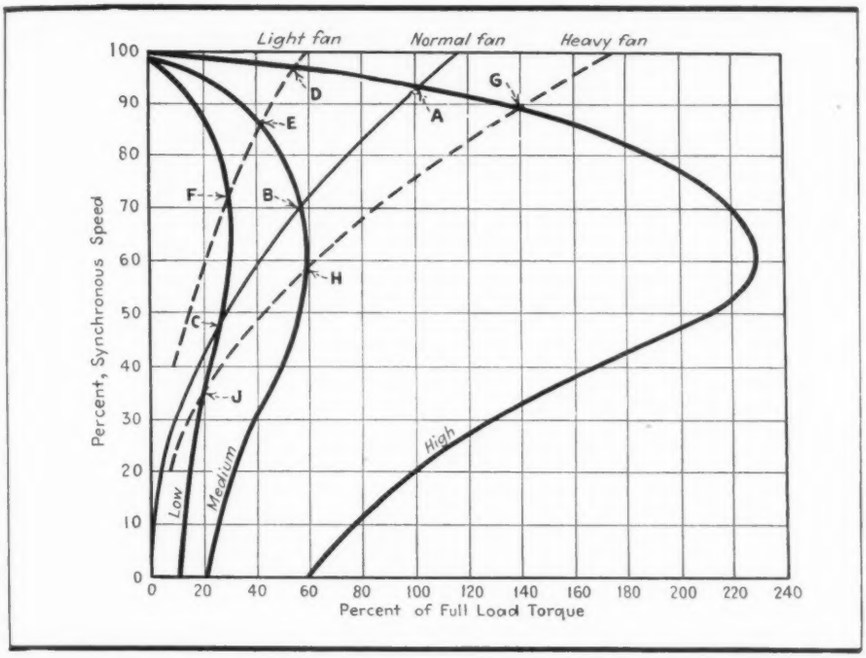


Fig. 10—The speed of a single-value capacitor motor is easily controlled by simply changing the voltage applied to the windings of the motor. The speed-torque curves for high, medium, and low voltage are shown. Driving a normal fan the speed for the high, medium and low voltage settings would be points *A*, *B*, and *C*, or about 93, 70, and 50 percent synchronous speed, respectively. A light fan would operate at points *D*, *E* and *F*, and a heavy fan, at *G*, *H* and *J*.

grams are given for a 110 volt or 220 volt single-value capacitor motor.

The single-value capacitor motors are often used for unit-heater applications and for any shaft-mounted fan with air flowing over the motor. The capacitor can be placed on the nose of the bracket, keeping the capacitor from interfering with the fan and permitting great flexibility in mounting the motor. For example, it can be used as a floor-mounted, ceiling-mounted, or round-frame, motor.

The single-value capacitor motor provides easy speed control of shaft-mounted fans, particularly for unit-heater drives.

Since the motor has two main windings, for normal operation the windings may be connected in parallel for 115 volts or in series for 230 volts. If connected in series and then operated on 115 volts the torque and operating speed are both reduced. This is a simple method for securing two speed control. Under these conditions, if the motor is driving a unit heater, the speed of the motor will decrease to the point where the torque required to drive the fan equals that produced by the motor.

More than two speeds can be obtained by using an autotransformer to impress selected voltages upon the motor. Fig. 10 shows the speed-torque curves of three

Table I—Maximum Inputs for 115-Volt 60-Cycle Single-Phase Induction Motors
(Currents for 230 volt motors are half of values shown)

Rating					Input						
			Output		General-purpose motors				Short-hour motors				Locked rotor amp.
					No Load		Full Load		No Load		Full Load		
Hp.	Poles	R.p.m. at full load	Watts	Torque, oz. ft.	Amp.	Watts	Amp.	Watts	Amp.	Watts	Amp.	Watts	
1/20	2	3,450	37.3	1.22	1.9	80	2.50	140					20.0
	4	1,725	37.3	2.44	2.0	59	2.30	117					20.0
	6	1,140	37.3	3.69	2.9	78	3.25	140					20.0
	8	860	37.3	4.89	4.2	97	4.40	166					20.0
1/12	2	3,450	62.1	2.03	2.1	80	2.70	167					20.0
	4	1,725	62.1	4.06	2.1	60	2.50	141					20.0
	6	1,140	62.1	6.14	3.2	80	3.60	167					20.0
	8	860	62.1	8.14	4.4	100	4.93	198					20.0
1/8	2	3,450	93.2	3.04	2.3	85	2.90	207	2.8	115	3.52	266	20.0
	4	1,725	93.2	6.09	2.3	62	2.70	176	3.0	120	3.38	227	20.0
	6	1,140	93.2	9.21	3.4	85	3.86	207	4.1	145	4.77	266	20.0
	8	860	93.2	12.21	4.9	110	5.40	245	5.8	185	6.75	311	20.0
1/6	2	3,450	124.3	4.06	2.5	95	3.18	254	3.4	150	4.32	318	20.0
	4	1,725	124.3	8.12	2.6	65	3.00	214	3.5	130	4.00	270	20.0
	6	1,140	124.3	12.29	3.8	95	4.32	254	4.9	155	5.69	318	20.0
	8	860	124.3	16.29	5.4	125	6.00	296	7.2	210	8.31	377	20.0
1/4	2	3,450	186.4	6.09	2.8	110	4.16	352	3.6	185	5.40	433	23.0
	4	1,725	186.4	12.18	3.3	90	3.86	301	4.3	150	5.07	365	23.0
	6	1,140	186.4	18.43	4.9	130	5.59	352	6.2	175	7.37	433	23.0
	8	860	186.4	24.42	7.3	175	8.10	414	9.2	235	10.81	504	23.0
1/3	2	3,450	248.6	8.12	3.2	140	5.27	460	4.4	220	6.55	540	31.0
	4	1,725	248.6	16.24	4.1	115	4.91	395	5.1	175	6.18	460	31.0
	6	1,140	248.6	24.6	6.1	179	6.97	460	7.0	205	8.31	540	31.0
	8	860	248.6	32.6	8.8	235	9.83	540	10.1	270	12.01	637	31.0
1/2	2	3,450	372.9	12.18	4.6	200	7.37	678	5.8	290	8.76	761	45.0
	4	1,725	372.9	24.4	5.7	160	6.90	574	6.9	215	8.31	643	45.0
	6	1,140	372.9	36.9	8.6	240	9.83	678	10.1	270	12.01	761	45.0
3/4	2	3,450	559.3	18.27	7.1	280	10.57	981	8.4	385	12.47	1,076	61.0
	4	1,725	559.3	36.6	8.3	220	9.93	835	9.9	285	11.58	917	61.0
1	2	3,050	745.7	24.4	9.1	340	13.5	1,265	9.1	410	15.90	1,360	

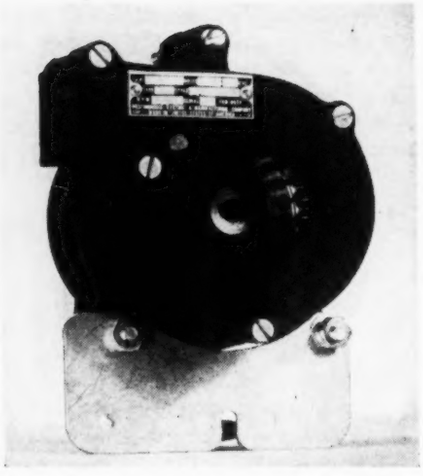


Fig. 11—Single-value motor and blower used for cooling electronic tubes. Powered from a single-phase circuit of 400 cycles, the motor turns the fan at 7,000 r.p.m. and delivers approximately 25 cu. ft. per min. in free air.

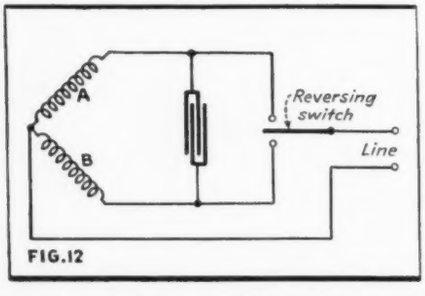


Fig. 12—Schematic circuit diagram of a simple method for reversing a single-value capacitor motor. The single-pole double-throw switch selects either phase *A* or *B* as the main winding, the other becoming the capacitor phase.

Table II—Minimum Torque Values for Single Phase A.C. Motors (From Nema Publication 45-102, June, 1945)

Hp.	R.p.m.	Split-Phase			Capacitor-Start		
		Locked-rotor	Pull-up	Break-down	Locked-rotor	Pull-up	Break-down
1/8	1,725 1,140	150 125	150 125	200 175	350 300	200 185	200 185
1/6	1,725 1,140	150 125	150 125	200 175	350 300	200 185	200 185
1/4	1,725 1,140	90 75	90 75	185 175	350 300	200 185	200 185
1/3	1,725 1,140				325 300	200 185	200 185
1/2	1,725 1,140				300 300	200 185	200 185
3/4	1,725				275	200	200

fans and the curves for the motor operating at three different voltages. For a given setting of the autotransformer, if the load is varying there will be a corresponding change in speed. As can be seen from Fig. 10, this type of control is not suitable in the light load range because the light load speed is practically the same for the different voltage settings.

An interesting war application of single-value single-voltage capacitor is the motor-driven blower for cooling vacuum tubes shown in Fig. 11. Another application of this type of motor is for rotating the anodes in X-ray tubes to improve their cooling, thus making possible the use of a higher voltage on the X-ray tube.

Single-value capacitor motors of the type shown in Fig. 12 are quite widely used for reversing applications because of the simplicity of their control. With only a single-pole double-throw switch, the motor can be started in either direction. Motors of this type use a balanced two-phase winding; direction of rotation is changed by using first one phase and then the other phase for the main winding, and using the remaining phase for the capacitor winding. Motors of this type are used for radio tuning, damper controllers, operating machanisms, induction regulators, pen-arm drive for small recording instruments and numerous similar applications.

In addition to the split-phase and capacitor types motors discussed in this article there are several other interesting types of small motors that are used by product designers. These include such types as shaded-pole, synchronous, and universal motors that will be discussed next month.

Cameras for Atom Bomb Test

PHOTOGRAPHING every detail of the forthcoming atom bomb test at Bikini Atoll, more than 24 Eastman high-speed motion-picture cameras, shooting at 3,000 frames per second, 10 spectroscopic and photometric cameras, and many aerial cameras with special filters and lead cases to protect them from radiation will be used. The shutters of these cameras must be synchronized to record in 0.025 second the blast and the devastating after-effects of the explosion. The spectroscopic and photometric units will be recording every thousandth of a second the intensity and the radiant energy of the explosion.

The method to be used involves standard aerial cameras with their lenses removed. The cameras will be directed at the general area of the explosion, and the film moved at high speed behind a slot over which step wedges of varying density and special filters will be attached.

Shown here is the K-22 aerial camera, with its 390 foot, 9½ inch roll of Kodacolor Aero film. To the right for comparison, is a Brownie Reflex camera with its roll of film.

ENGINEERING ABSTRACTS

FOREIGN AND DOMESTIC ARTICLES

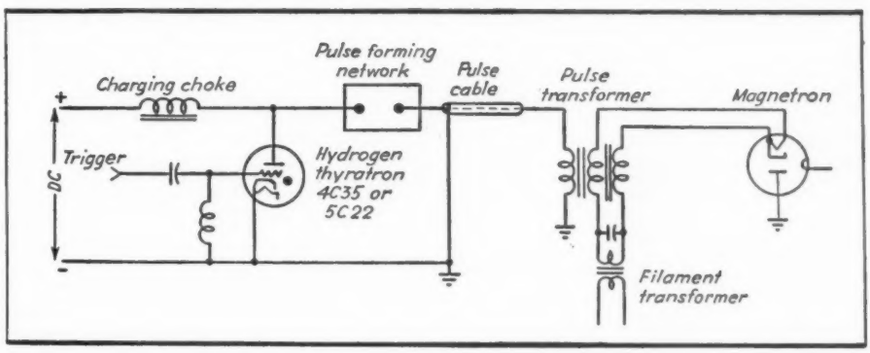
The Hydrogen Thyratron

From a conference paper, "The Hydrogen Thyratron" by H. Hein, electronic engineer, Sylvania Electric Products Inc., delivered at the Winter Convention of the American Institute of Electrical Engineers in New York City.

HYDROGEN THYRATRONS were highly developed during the war as pulser tubes for radar and their possible peacetime uses may include: 1. Commercial radar navigational aids for ships and aircraft. 2. Pulsed microwaves supplying heat for forming, bending, and sealing glass. 3. Pulsed microwaves for forming and joining certain plastic materials. 4. Pulse communication systems with multichannel operation. 5. High speed welding using precisely spaced pulses of microwave power. 6. Pulse techniques for increasing speed of electroplating and making possible denser platings since depolarization effects may be avoided. 7. Replacement of spark gap in that type of induction heater, diathermy machines and electro-surgery equipment. 8. High speed sweep circuits. 9. High speed photography technique that uses the thyratron to flash a gas discharge tube at frequences of 5 to 6,000 times per second.

The order of magnitudes of the pulse characteristics used in radar systems may be of interest. Peak network voltages range from 5 to 30 kw., peak currents from several amperes to 250 amp., repetition frequencies from a few hundred to 4,000 pulses per second, and pulse width on times of 1/10 to 6 microseconds. It is evident that the tubes switch relatively high peak voltages and currents. The peak powers involved reached power levels of 2 or 3,000 kw., but because of the short pulses the average power levels are of the order of 1/1000 of the peak power levels.

The fundamental structure of hydrogen thyratrons for different power levels is similar. The anode is a molybdenum disk completely enclosed by and closely spaced from the grid structure. This spacing is considerably less than the mean free path in hydrogen at the operating temperature and is responsible for the high operating voltages attained. The control element of the grid structure is a perforated disk below the anode. A baffle mounted below the grid disk gives the tube its positive control characteristic and greatly reduces ion bombardment of the cathode. The special anode seal to meet the temperature and voltage requirements. An equipotential cathode with radiation shields is used.



Thyratron Line Modulator. The thryatron is controlled by applying a trigger voltage of desired repetition rate to its grid. Pulses transmitted over the pulse cable feed a special impedance matching transformer. The pulse transformer steps up the voltage 4 or 5 times, providing the higher pulse voltage required by the magnetron. Because of the matched impedance of the pulse cable, the magnetron can be placed physically at any desired position. By proper circuit design, tubes can be operated in series to increase the voltage or in parallel to increase the current.

Use of hydrogen introduces many difficulties in tube processing. Hydrogen is very active and is readily absorbed by most metals and by carbon. This requires saturating the metal parts with hydrogen to prevent rapid cleanup. Also hydrogen will react with substances such as metallic oxides or carbon to produce products capable of poisoning the cathode. Extraordinary cleanliness of parts and complete freedom from contamination, is of great importance.

An extremely important factor is the purity of the nickel, particularly that for the cathode. Comprehensive tests on tube performance supplemented by chemical and metallagraphic analysis are required to identify impurities. Before satisfactory initial production was obtained a grade of highly purified nickel, far superior in purity to the best grades of nickel used commercially in other tubes, was developed in cooperation with a manufacturer of nickel.

Hydrogen is also capable of reducing the barium oxide of the cathode coating if the cathode temperature is too high. This restricts the operating temperature range to a narrow region in the vicinity of 800 deg. C. since difficulties with emission occurs if the cathode temperature is designed to run low to avoid barium oxide reduction. A peep hole is provided in the structure for determining cathode temperatures with an optical pyrometer.

The life of the hydrogen thyratron has improved continuously. Although the joint Army-Navy Specifications call for a life of 500 hr., which was difficult to meet originally, the present life is now over 2,000 hr. and further design changes are being tried which may increase the life to 5,000 hours.

Basic Characteristics of Magnesium

From "The Industrial Significance of the Basic Characteristics of Magnesium" by J. D. Hanawalt, Dow Chemical Company, presented before the Engineering Society of Detroit, Jan. 4, 1946.

A STRIKING FACT about magnesium is that the metal is potentially the world's most universally available. It is more abundant in high grade ores, which are widely distributed over the earth, than iron or aluminum. In addition all of the magnesium made in the world to date could have been

taken from about one-tenth of a cubic mile of sea water.

Four and one-half inch rocket launching tubing was continuously extruded on a 5,000-ton press at the rate of 80 ft. per min. Magnesium has limited cold but superior hot workability. To form magnesium sheet on a drop hammer instead of a press is commercially feasible. Technique of spinning and roll-forming, well known for other metals, are working out to advantage with magnesium with the introduction of temperature control. Welding, whether gas or electric, can be done efficiently.

Comparable data on cutting speeds, power requirements, tool life, and surface finish indicate that magnesium is the most machinable of structurable metals. The problems in magnesium are no greater than those in the steel industry.

Magnesium provides design economies. One of the most common is the example in which a different design permits a casting to be used instead of a fabricated assembly. This is usually achieved through the use of thicker sections without the penalty of added weight and often with a saving in weight.

The modulus of elasticity in millions of lb. per sq. in. of magnesium is 6½, aluminum 10, and steel 29, so that section for section magnesium is deflected proportionally more under the same load. In spite of this, structures in magnesium can be the more rigid for equal weight if an increase in the dimensions is permissible.

In the average outdoor rural and industrial atmosphere magnesium is stable. After 15 years bare magnesium parts will have formed a gray adherent oxide coat and at most will have lost 10 to 15 percent of their strength. If painted with standard synthetic paints, they will undergo no loss in properties. Magnesium canoes have been used in many parts of this country and Canada with no corrosion troubles.

Stability of Phenolic Plastics

From "Stability of Phenol Formaldehyde Plastics" by F. A. Martin, The Hoover Company, presented at the annual meeting of the Society of Plastic Engineers, January 9, 1946.

THIS WORK was undertaken to find the answer to a specific problem—the reported growth of some molded parts that were stored for three or four years. When the plant tried to assemble these parts with other component parts, it was found that they had grown as much as 0.018 in. on an overall dimension of 5 in., indicating a growth of about 0.0035 in. per inch. It was thought that this growth was caused by moisture absorption from the air. The influence of storage under different relative humidity conditions, therefore, was investigated.

The chart, Fig. 1, shows the relative water resistance of various plastics, based on data taken from the Plastics Materials Manufacturers Handbook. The different materials roughly group themselves into three classifications. On the left are the members of the cellulose family, with relatively high water absorption.

The thermosetting materials, the ureas, the phenolics and the malamines, are somewhat less water absorbent and the methacrylates, vinyl chloride acetates and polystyrene are relatively unaffected by the water. A possible explanation for the water absorption in the cellulose family is the fact they contain plasticizers which may be displaced by water. The thermosetting materials contain fillers such as wood flour or cotton flock. These fillers probably are quite well protected by the resin, so that it is difficult for the water to reach the filler, making the thermosetting materials more resistant to moisture than the cellulose plastics.

The third class, the methacrylates, vinyl polymers and copolymers and polystyrene, contain neither filler nor plasticizer. Here the water works on the resin alone, therefore the water resistance is usually excellent.

While there is a great deal of data in the literature on the behavior of plastics totally immersed in water, there is very little on the effect of water vapor in the air on dimensional stability, particularly of the phenol formaldehyde plastics.

Most investigators, before measuring water absorption, conditioned the samples to a bone dry state, either by heating in an oven or by storing in a dessicator or combination of the two methods. For this work, however, the test samples were used in the as-molded condition, since it was not thought desirable to create conditions that did not exist in the plant.

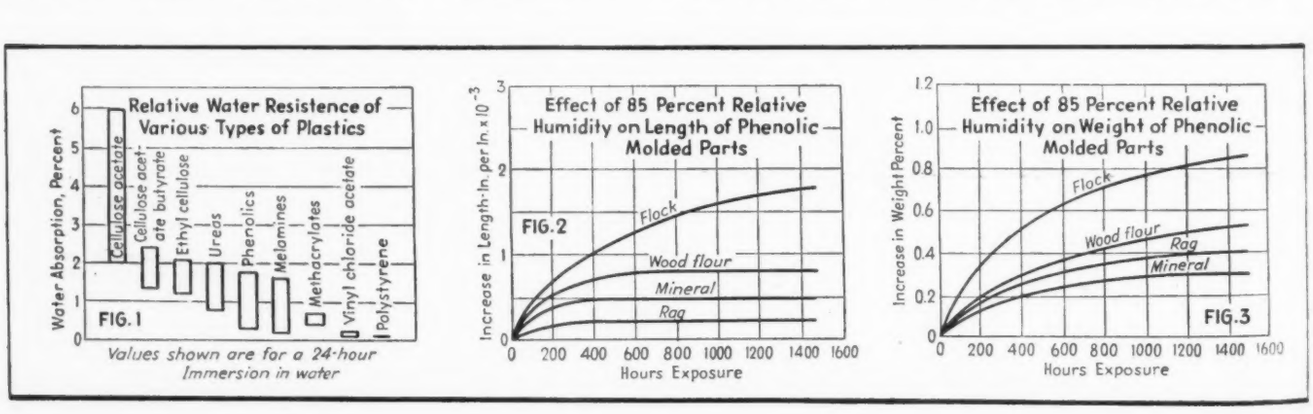
Molded bars 1/2 in. by 1/2 in. by 2 1/2 in. long were used. Such pieces were chosen for two reasons: first, because of the simplicity of the measurement of dimensional changes, and also because of the availability of such pieces molded from a wide variety of materials.

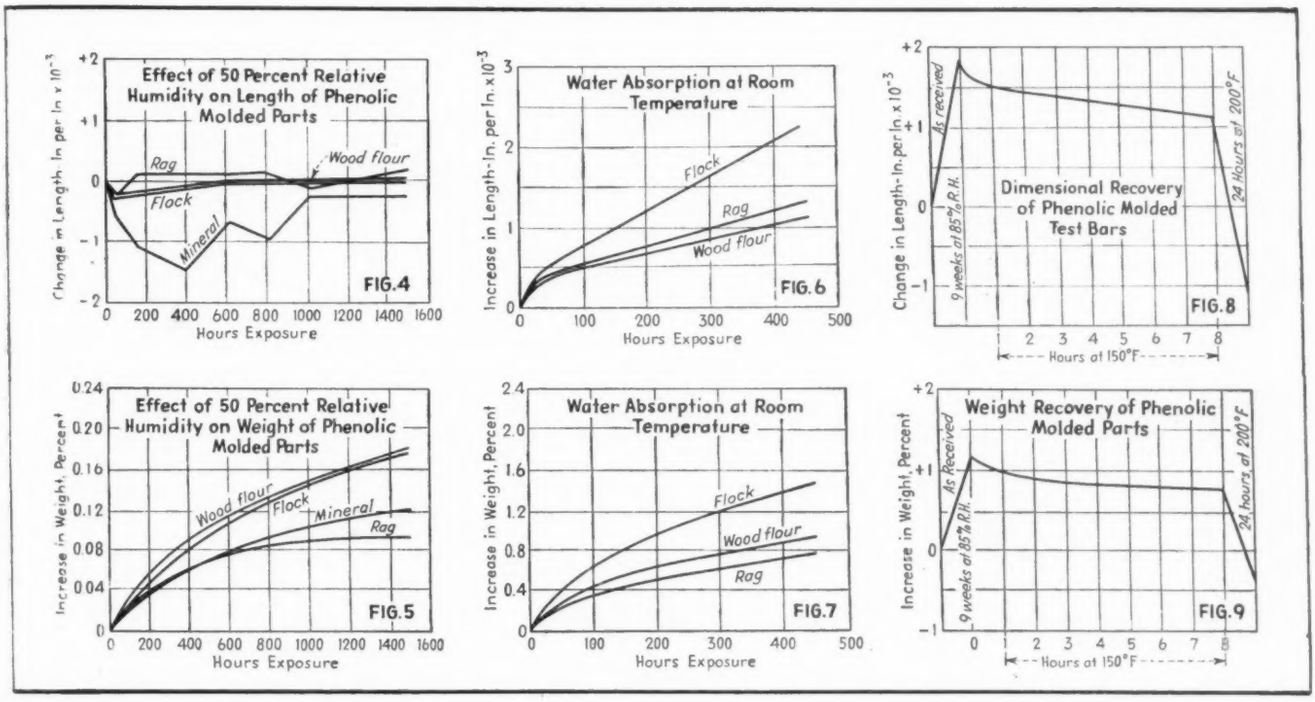
Length was measured with a micrometer caliper and the readings estimated to 0.0001 in. Weight measurements were made on an analytical balance to the nearest one-half milligram, giving an accuracy of one part in thirty thousand.

After initial length and weights were measured, the samples were stored in constant relative humidity cabinets at 85 percent relative humidity and 50 deg. F., and 85 percent relative humidity and 55 deg. F. The samples were stored in a single layer on a perforated metal sheet, not touching on another, so that the air could circulate freely between them. Periodically the samples were removed from the humidity cabinets and replaced after having been measured. Dimensional and weight changes were plotted against time of storage. After equilibrium conditions had been reached, some samples were dried out in an electrically heated oven and the humidity test was repeated.

Although 85 percent relative humidity may seem high, over a large portion of the United States the relative humidity may run as high as 85 percent for a great deal of the time. The relative humidity in heated factories will not average 85 percent, but molded parts may be stored for long periods in unheated warehouses where the relative humidity is 85 percent or higher. The experiments proved that the relative humidity is high enough for appreciable changes to take place in both dimensions and weight.

Increase in length of the test bars stored at 85 percent relative humidity and 85 deg. F., plotted against the time of exposure, is shown in Fig. 2. The results are the average of a number of samples, representing commercial materials marketed by different suppliers. The type of material with which the resin is filled plays a part in the amount of water absorption. Cotton flock filled materials show the greatest increase in length. This is probably caused by the fairly long cellulose fibers conducting vapor into the





test pieces by means of capillary action.

Mineral filled materials show a smaller dimensional change than a wood flour or cotton flock filled material, since the minerals themselves are not affected by moisture. It is interesting to note, however, that the rag filled materials showed a lower dimensional change than the mineral filled materials. Mr. Martin's explanation is that in the rag filled materials the filler forms an interlocking network that makes it difficult for the resin to expand.

Increase in weight of the same samples stored at 85 percent relative humidity is shown in Fig. 3. Here again the flock filled materials show the largest gain in weight, followed by wood flour, rag and then mineral The positions of the rag filled and mineral filled material are reversed. In about six hundred to eight hundred hours, at 85 percent relative humidity, the moisture absorption is about the same as in a hundred hours of total immersion.

Change in length of the four types of phenolic plastics when exposed to 50 percent relative humidity is shown in Fig. 4. The curves are irregular and the change in length is negligible. It is safe to conclude from this data that the phenol formaldehyde plastics are dimensionally stable at 50 percent relative humidity.

Percentage increase in the weight of the samples stored at 50 percent relative humidity is shown in Fig. 5. Since this weight scale is five times that of the chart showing the increase in weight at 85 percent relative humidity, the moisture gain is actually small.

Data on water absorption on some of the same materials at room temperature are included, for comparison of the swelling effect at 55 percent relative humidity. Fig. 6 shows the increase in length of the flock filled, rag filled and wood flour filled materials. No mineral filled samples were available for these tests, but they would certainly have shown the lowest water absorption.

It appears that swelling in water only takes place from two to four times as fast as in air at 85 percent relative humidity. Fig. 7 shows the increase in weight of samples immersed in water.

The salvaging of parts which become oversize from moisture absorption was the investigated. Fig. 8 shows what happens when the same 1/2 in. by 1/2 in. moisture laden test bars were dried in an oven. This curve represents the average of five wood flour materials, two samples of each. After nine weeks at 85 percent relative humidity, the test bars had increased in length about 0.0018 in. per inch. When these bars were then placed in an oven at 150 deg. F. the length started to diminish, and at eight hours the bars had shrunk about 0.0011 in. per inch.

The same type of data regarding weight is shown in Fig. 9. After eight hours at 150 deg. F., the gain was reduced to 0.75 percent, and after twenty-four hours at 200 deg., the weight was about 0.4 percent under the original weight. These two charts show that it should be possible to restore, by a simple heat treatment, the original dimensions of phenolic parts.

Test bars were then stored under normal laboratory atmospheric conditions and their length and weight measured, as previously. After twenty weeks, there was no appreciable change in length or weight. The average relative humidity in the laboratory during this period was about 33 percent.

Other investigators have reported what might be termed a skin effect in the water absorption values. If the molded surface is broken the water absorption is increased. This was observed also at 85 percent relative humidity. One production part on which the surface finish was broken showed a water absorption 1.36 percent after twenty weeks at 85 percent relative humidity. This compared with an average of about 0.9 percent for a number of unused parts with the molded surface intact. Experiments indicated that cure has no effect on the rate or the quantity of water absorbed.

Shot Peening and Fatigue Strength

From "Shot Peening and the Fatigue of Metals", by Dr. H. F. Moore, published by the American Foundry Equipment Co., Mishawaka, Indiana.

IN SHOT PEENING the surface of a metal machine part or structural member, the shot is released from the rotating blades of a wheel, or ejected by an air blast and upon striking the surface of the part, it distorts the crystalline structure of a shallow layer of the metal. This shallow layer of metal is made harder, stronger and less ductile than it was in the pre-peened state, and somewhat harder, stronger and less ductile than the metal farther below the surface, although the metal just below the shot-peened layer is somewhat affected by the shot peening. The effect of this on the five types of failure that may occur is as follows:

(1) EXCESSIVE ELASTIC DEFORMATION. As an example, a clutch plate spring may be made too light, so that even when the

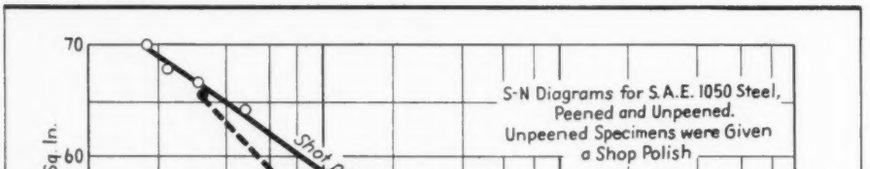


plate spring is flattened, the clutch will not transmit the required power. Shot peening would not be of service in such a case; it would change only slightly the modulus of elasticity of the metal in the spring, and would not stiffen the spring so long as it was stressed within the elastic range of the original metal.

(2) Elastic Buckling, such as may occur in very long posts or columns. This is another case of failure, or at least the beginning of failure, which takes place within the elastic range of the metal. A long, slender column when compressed lengthwise will begin to buckle before the metal is stressed beyond its elastic range. Here, too, shot peening will be of very little aid. The critical load that will start elastic buckling will depend, not on strength, but on the modulus of elasticity of the metal, which will be very little changed by shot peening in the case of iron and steel, and not greatly changed for most other structural metals. Note again that this is elastic buckling, not buckling after the metal has passed beyond the range of elastic strength into the range where the deformation is partly plastic.

(3) Plastic Deformation. Deformation of a machine part which remains as "set" after load is removed is in itself structural damage. In short and in medium-length columns plastic deformation reduces the stiffness of the metal and buckling follows. In statically loaded structural members failure by plastic bending under compressive stress (exceeding the yield strength in compression) is probably the most common type of structural damage due to stress. Shot peening increases the yield strength (resistance to plastic deformation) to a marked degree in the skin of the peened metal, and thus adds strength to resist plastic deformation in the outer layers of a structural part, where the applied bending stresses are greatest. This increase of yield strength may be partly or wholly lost however, if the peened metal is subject to subsequent stresses up to or beyond the yield strength.

(4) Creep. Creep is the continuing distortion of a material under a steady load. Damage by creep is similar in character to damage by plastic deformation, but creep continues, while simple plastic distortion does not increase or at only a negligible rate after a few moments of load. Little is known about the effect of shot peening on creep.

(5) Fracture. Fracture takes place under tensile or shearing stress. While plastic deformation and creep involve appreciable volumes of metal before appreciable structural damage is done, fracture may start at some point of localized stress concentration, such as a sharp shoulder on a shaft, and from that nucleus a crack may spread upon repeated loading and fracture the piece.

Such a fatigue crack usually starts under shearing stress within one or more of the crystalline grains which make up a piece of metal. However, as the crack spreads in a region of tensile stress, it soon takes up a direction at right angles to the principal tensile stress. In a region of compressive stress the crack frequently follows a direction of maximum shearing stress, and the crack progresses much more slowly than it does in a region of tensile stress. In structural metals increase of tensile strength is accompanied by increase of shearing strength, and so any process which increases tensile strength usually increases resistance to "fatigue," although not necessarily proportionately.

Shot peening "cold works" the metal at or near the surface of a piece. Cold work affects the fatigue strength of a metal in two ways: (a) it may set up a thin skin of metal which is under stress, in some cases compressive and in other cases tensile. If that stress is tensile it will be a weakening factor, if compressive it will be a strengthening factor. This residual stress is distributed across the cross-section of the piece in a regular pattern, and extends through the entire length subjected to the cold working. It is a large-scale or "microscopic" effect. (b) Cold work, however produced, makes changes in the shape and orientation of crystalline grains of the metal, and, unless the cold work is so violent as to cause incipient cracks, the metal is strengthened and enough ductility remains to prevent cracking. This second effect is a small-scale "microscopic" effect, and it is scattered throughout the cold-worked metal and possibly extends a short distance beyond the depth of cold working. It is a summation of many localized disturbances with resulting stresses within and between crystalline grains.

Shot peening increases the tensile strength of a metal just below the surface, and in addition, sets up a longitudinal compressive stress in the thin "skin" of shot-peened metal. It probably also sets up stresses in a transverse direction and in a direction perpendicular to the surface. Now a fatigue crack nearly always starts on the tension side of a beam, and hence the longitudinal residual compressive stress must be overcome by applied stress before the stress on the tension side of the beam will be a net tensile stress. In effect the beam is strengthened materially against fatigue failure by this layer of metal under residual compressive stress so long as that stress is not removed by subsequent working stresses. Hence shot peening acts in two ways to increase the fatigue strength of the metal: (a) The tensile strength of the skin is increased and (b) the effective tensile stress set up by a given load applied stress is diminished by the compressive stress set up in the skin by shot peening.

On the other hand, shot peening roughens the surface, and thus produces many shallow pits which cause localized regions of stress concentration, which tend to lower the resistance to fatigue. If care is taken to prevent formation of jagged edges, however, numerous fatigue tests show that the strengthening effect of shot peening properly done is, in general, greater than the weakening effect of the roughened surface, and that shot peening increases by a considerable percentage the resistance of a metal to fracture under repeated stress.

Dynamics of Elastic Buckling

From "On the Dynamics of Elastic Buckling," by J. H. Meier in *Journal of the Aeronautical Sciences*, October, 1945, published by Institute of the *Aeronautical Sciences*, 2 E. 64th St., New York 21, N. Y.

Although the problem of buckling under impact must confront many engineers there seems to be little information available on the subject.

Based on the equilibrium of external and internal bending moments, the classic theory of elastic buckling does not consider the time elements and the inertia forces present.

The author investigates the time-deflection

relations when an axial force is rapidly applied to a nearly straight bar. Distinction is made between (1) when the force applied is smaller than Euler's load for elastic buckling; and (2) when the applied force is greater. The investigation is limited to cases where the center deflection of compressed bars stays relatively small with respect to the length of the bars. Damping is not considered in this analysis, but where it is of importance and the damping constants can be established, a correction factor can be applied to the equations given.

Constant-Speed Drives for Aircraft Alternators

From "Constant-Speed Drives for Aircraft Alternators", by C. J. Breitwieser, design engineer in charge of radio electrical engineering, Consolidated Vultee Aircraft Corporation. Published in the Transactions Section of the November, 1945, issue of *Electrical Engineering*, 29 W. 39th St., New York, N. Y.

ALTHOUGH the main engines of an airplane may vary from 500 r.p.m. at idling to 3,000 r.p.m. at military power, variable-ratio couplings supply practically constant speed to the electric alternators driven by the main engines.

Two infinite-ratio coupling systems with positive translations are fully described and explained. One is a unique mechanical system developed by the Chrysler Corporation, and the other is a hydraulic design, such as built by the Sundstrand Machine Tool Company. Because these systems do not depend upon slip, their efficiency is high.

The units discussed have been at least in experimental production and give some idea of future constant-speed drives for large aircraft. Production units of constant-speed drives will probably: (1) Be 85 to 95 percent efficient; (2) weigh less than one pound per transmitted killowatt; (3) hold a preset output speed to within 1 percent total variation with a 500 to 3,000 r.p.m. input speed range; and (4) fit within a space of 50 cu. in. per kw. of rating. Larg. airplanes of today with a.c. systems will use such drives; future refinements that increase efficiency and reduce size and weight may make constant-speed drives suitable for d.c. generators and other auxiliary equipment.

Spring Gradient

From "What is Meant by the Gradient of a Spring," *The Mainspring*, December, 1945, published by Wallace Barnes Co., Division of Associated Spring Corp., Bristol, Conn.

A SPRING GRADIENT of five lb. per in. means that the spring deflects one in. under a load of five pounds. The gradient, considered important in many fields, is given the symbol K. It is expressed by:

$$K = P/F = Cd^4/8D^3N$$

where P is the load in lb., F is the deflection in in., G is the torsional modulus of the material, d is the diameter of the wire in in., D is the mean diameter in in. and N is the number of active coils.

Designers should specify the fewest possible requirements. The specification of two load tests is a gradient test. Enough space should be left in the design so that the solid height can be increased if necessary. Or the stress can be held low enough so that the wire size can be decreased to meet the specifications. Good practice is to allow ten percent of the total deflection between the solid height can be increased if necessary.

Pigment Dispersion in Synthetic Rubber Latex

From "Pigment Dispersion in a Synthetic Rubber Latex" by W. McMahon in *Bell Laboratories Record*, December, 1945, published by Bell Telephone Laboratories, 463 West St., New York 14, N. Y.

THE USEFULNESS of most synthetic rubber compounds depends largely on the reinforcing fillers or pigments in them. Physical properties of GR-S, the synthetic now being manufactured in large quantities for civilian use, would be inferior to natural rubber except for the reinforcing fillers. Fine carbon blacks give the greatest ultimate tensile strength.

The reinforcement obtained with a given pigment is proportional to the degree of its dispersion in the mixture; also the size of the particles have a marked effect. To obtain better dispersion reinforcing pigments were experimentally incorporated in GR-S polymers while in the latex stage. Typical improvements in physical properties are shown in Fig. 1. Similarly, the strength of latex-dispersed zinc oxide and calcium carbonate compounds of GR-S are greater than mill-mixed samples. The electrical properties of latex-dispersed whiting compounds are better in all respects to those of the same compounds dispersed on a mill as shown by Fig. 2.

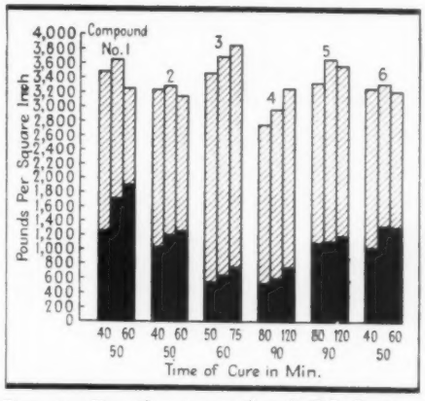


Fig. 1—Tensile strength of GR-S synthetic rubber compounds (1, 3, 5) made with latex-dispersed carbon black are superior to those (2, 4, 6) in which the filler is mixed on a mill. Black areas show tension required to produce 300 percent elongation.

These experiments show that insulating stocks, particularly those other than black, can be made which have physical properties considerably better than are obtainable by present methods. Improvement may also be expected in automobile tires, and one tire manufacturer already has inaugurated this process in a synthetic rubber plant. Another advantage is cleaner handling in the factory, since no dusting of pigment occurs when it is master batched in the polymer. Incorporation of pigment in the latex stage may also prove to be more economical than mill dispersion.

The saving of power in the manufacturing process and the increase in productive capacity of a factory unit, which is effected by shortening the time required for milling, may more than offset the cost of the latex pigmentation process.

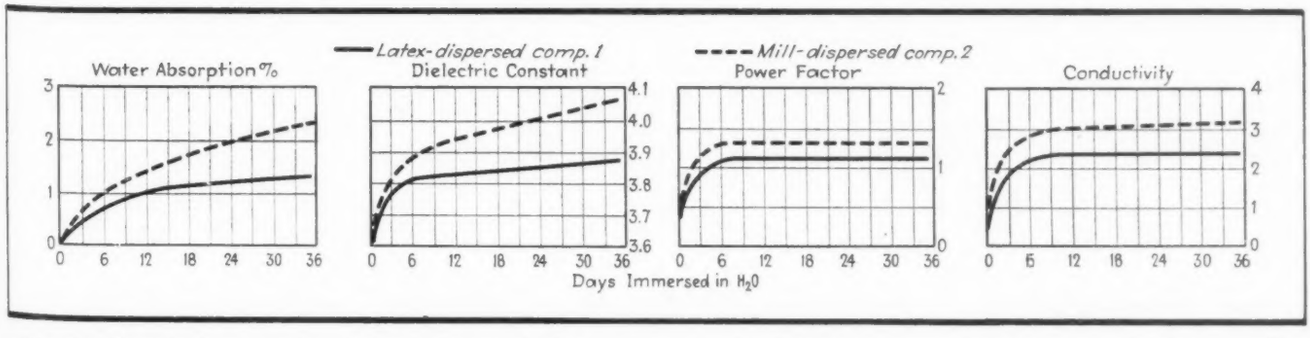


Fig. 2—Electrical properties of latex-dispersed whiting compounds of GR-S are superior to those mixed on a mill.

INDUSTRY AND SOCIETIES

RESEARCH—STANDARDS—PATENTS

International Unification of Engineering Standards

Agreements Reached in Three-Country Conference

RESULTS OF THE INTERNATIONAL CONFERENCE on unification of screw thread and other engineering standards held last October at Ottawa were recently released by the Combined Production and Resources Board.

This conference was the culmination of months of concerted technical effort on the part of national engineering committees working through the British Standards Institute, the Canadian Standards Association, and the American Standards Association. Unification of engineering standards had been agreed on, in principle, at a conference in London, August-September, 1944. A technical basis was laid for such unification at the Ottawa conference. The report that came out of the conference consists essentially of recommendations to the industries of the three countries as to how they may carry out the work of unification.

All recommendations of the conference have been referred to committees of the national standardizing bodies of the three countries with a view to their use in development of the national standards. The American Standards Association, working under the technical leadership of the American Society of Mechanical Engineers and the Society of Automotive Engineers will reduce these recommendations to the usual terminology of American Standards. The technical detail is to be identical in the standards of the three countries, thus providing for complete interchangeability of parts.

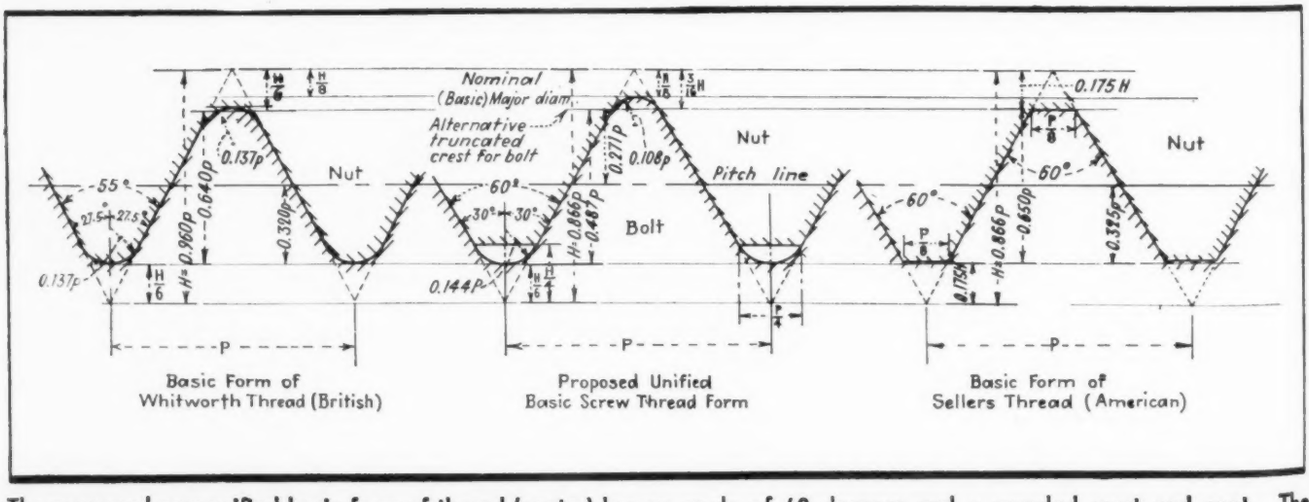
Screw Thread Unification

The American thread system, originally developed by William Sellers for whom it is named, has a thread form with a 60 degree angle; while the British, called the Whitworth system, has an angle of 55 degrees. There are also other important differences. The pitches of the British fine thread are coarser than the pitches of the American fine thread. Fortunately the pitches of the coarse thread are the same except in the half-inch bolt for which the British have twelve threads per inch and the Americans thirteen. The Whitworth screw has a rounded top and bottom and the Sellers screw a flat top and bottom.

The new basic form of thread which was endorsed by the conference has an angle of 60 degrees and rounded crest and root, with truncation of the crest of the screw permissible. Threaded products made to this new form will be practically interchangeable with those having the same nominal diameter and pitch made to the present American Standard. On the part of the British, however, a change in the thread angle from 55 to 60 degrees for threads of all sizes will be necessary.

This proposed form recommended as a standard is the result of efforts to retain the best features of the present forms. At the same time a series of associated diameters and pitches have been worked out which it is believed will simplify existing practice and yet provide an adequate range of choice for all general requirements. (See accompanying tables for data on small and regular screw thread series.) It is also felt that the proposed change will involve a minimum amount of departure from existing practice consistent with obtaining a common standard for general purpose threads. The basic form of thread is being considered by sectional committee B-1 of the American Standards Association.

A further agreement was reached in Ottawa on a proposed system of coarse threads in nominal sizes from 0.086 in.



The proposed new unified basic form of thread (center) has an angle of 60 degrees and a rounded crest and root. The radius of the root of the screw is larger than the radius of its crest. Truncation of the crest of the screw is permissible.

Chairman of U. S. Delegation—Elmer J. Bryant, Director of Research, Greenfield Tap and Die Corporation, is chairman of the American Standards Association Committee on Screw Threads.

Chairman of British Delegation—Stanley J. Harley, Director of the Coventry Tool and Gauge Co., is Director for Jigs, Tools and Gauges for the British Ministry of Production and Supply.

Chairman of Canadian Delegation—James G. Morrow, Chief Metallurgist, Steel Company of Canada, Ltd., is chairman of the Canadian Standards Association.

(American Standard size No. 2) to 4 in., and fine threads in nominal sizes from 0.086 in. 1½ in. Here, the Americans have made some concessions by agreeing to one change in diameter (0.216 to 0.220 in., for the No. 12 size), and five changes in pitch. The most important of these changes is in the pitch of the ½ in. coarse thread, from 13 to 12 threads per inch. The British will have to change the pitches on *all* sizes of their fine threads, ranging from ¼ to 1½ inches in diameter.

In addition to the agreement on a unified basic form of thread, agreements were reached on special purpose threads, including acme threads, buttress threads for fastening screws for precision instruments.

ACME THREADS. Following the London conference in 1944, the American War Standard for Acme Threads (the piano stool thread), B1.5-1945, had been placed in final form and forwarded to the United Kingdom and Canada for review. This standard has been adopted in all three countries although the method of presenting the data is somewhat different in the British publication from that followed in the United States and Canada. Also, in accordance with the agreements reached in London, the American committee had developed a specification for Stub Acme Threads.

BUTTRESS THREADS. A standard form of buttress thread was agreed upon, particularly designed for use in applications involving exceptionally high stresses in one direction only. The agreements also included preferred series of diameters and pitches, formulas for calculating suitable tolerances and allowances, and a recommended system of gaging. The thread form has an over-all depth of engagement of 0.4 pitch, a pressure face angle of 7 degrees and the pressure face and back face connected by symmetrical radii of suitable proportions. The formula for calculating the effective diameter was the same as that used in British Standard 84-1940 (Whitworth) but modified to suit the buttress thread and to compromise the pitch-diameter factors to meet the wide range of pitch-diameter relationships.

An alternative form with a vertical pressure flank thread was in demand, the British found, particularly for larger gun work and on high pressure steam valves. An appendix added to the draft standard therefore provides an alternative optional thread form having a vertical pressure flank.

It was also agreed at the conference that the method of calculating tolerances and allowances on buttress threads as given in the British proposal should be accepted with the reservation that it is open to revision in accordance with any general change in basic formulas for tolerances and allowances in a unified standard for screw threads.

HIGH DUTY THREADS. While all three countries have made considerable progress in the London conference in the way of assembling engineering data, it was quite evident that the diversity of practices on establishing tight fits between threads on steel studs and tapped holes in aluminum and magnesium castings and forgings, did not permit of the formulation of definite recommendations at Ottawa. The conference has found that there is still need for much exploratory work in this field. It is understood that the British will review in due course British standard 1171, which is based on standard studs in conjunction with undersize holes. In the United States, the standard of the Society of Automotive Engineers ARP 142 will continue in use. In this standard the minimum hole is basic size and the stud is oversize. Studies as to the necessity of relating interference with grades of hardness met with in various light alloys will be continued.

PIPE THREADS. An American subcommittee had developed a proposal of "International" pipe threads intended as a compromise between British Standard Pipe Threads and American Standard Pipe Threads, in the range of nominal sizes below four inches. Since no consensus of this proposal had been

Table I—Small Screw Thread Series Proposed Basic Screw Thread Form (60 deg. included angle)

Designation	Basic major diameter		Pitch mm.	Approximate Threads per in.[1]
	Mm.	Inches		
039[2]	1.00	0.0394	0.25	102
043	1.10	0.433	0.25	102
047[2]	1.20	0.0472	0.25	012
051	1.30	0.0512	0.25	102
055[2]	1.40	0.0551	0.30	85
059	1.50	0.591	0.30	85
067[2]	1.70	0.0669	0.35	72½
071	1.80	0.0709	0.35	72½
079[2]	2.00	0.0787	0.40	63½

[1] Multiple relationships of 127. [2] Preferred sizes.

reached in the United States, the United States delegation could merely discuss this subject as a technical matter, without being able to make any formal commitments. It is intended to continue the discussions.

Consideration is being given also to the adoption of the international series of pipe threads in nominal sizes of four inches and larger. In this range, the American Standard is widely used since it has been adopted by the American petroleum industry and thus has spread out throughout the world. After the Ottawa Conference, this subject was discussed further between the British delegation and an American Petroleum Institute Committee at a meeting held in Chicago.

SCREW THREAD NOMENCLATURE AND SYMBOLS. Agreement was reached on a series of Proposed Screw Thread Symbols, including General Symbols and Pipe Thread Symbols. It is the intention that these symbols be used in all American War Standards and American Standards to be developed from now on.

INSTRUMENT THREADS. Items on which agreement for unification was reached in this field are: Threads for fastening screws; Fine-motion screws; Micromatic screws; Threads for optical tubes and cells; Microscope objective thread (interchangeable with the widely used Royal Microscopial Society thread).

These agreements on instrument screw-threads were based on the Swiss Horological Society standards and it was decided that gaging practices for small screws should be discussed with the Swiss. For fine motion the new basic form of thread was proposed, possibly with decimal inch diameters, particularly for sizes below ¼ inch.

Limits and Fits

The American delegates reported to this conference that having been unable to secure agreement on a standard based on the full British proposal, it was prepared to present for discussion the proposed American Standard B4 of July, 1945, on Limits and Fits for Engineering and Manufacturing containing definitions of terms applying to fits between plain parts; a table of preferred basic sizes; a table of Preferred Allowances and Tolerance; the unilateral system of tolerances and a standard reference temperature.

While it was not possible at this conference to develop complete agreement, much progress has been made in establishing a series of definitions. This will enable those interested in the subject to uniformly interpret the language of the standards of the three countries. It has also been agreed that some provision be included in the standards which will give to the designer a guide where conditions precluded the possibility of following the preferred basic sizes listed in the British and American proposals.

Table II—Small Screw Thread Series Proposed Basic Screw Thread Form (60 deg. included angle)

Designation	Basic major diameter (in.)	Threads per in.	
		Coarse	Fine
086	0.0086	56	64
099	0.099	48	56
112	0.112	40	48
125	0.125	40	44
138	0.138	32	40
164	0.164	32	36
190	0.190	24	32
220	0.220	24	28

Table III—Regular Screw Thread Series Proposed Basic Screw Thread Form (60 deg. included angle)

Nominal size (in.)	Basic major diameter (in.)	Threads per in.	
		Coarse	Fine
1/4	0.250	20	28
5/16	0.3125	18	24
3/8	0.375	16	24
7/16	0.4375	14	20
1/2	0.500	12	20
9/16	0.5625	12	18
5/8	0.625	11	18
3/4	0.750	10	16
7/8	0.875	9	14
1	1.000	8	12
1 1/8	1.125	7	12
1 1/4	1.250	7	12
1 3/8	1.375	6	12
1 1/2	1.500	6	12
1 3/4	1.750	5	—
2	2.000	4 1/2	—
2 1/4	2.250	4 1/2	—
2 1/2	2.500	4	—
2 3/4	2.750	4	—
3	3.000	4	—
3 1/4	3.250	4	—
3 1/2	3.500	4	—
3 3/4	3.750	4	—
4	4.000	4	—

Drawing Practice

The sessions on drawing practice were devoted to a discussion of the paper by Mr. C. A. Gladman of the (British) National Physical Laboratory, entitled "Drawing Office Practice in Relation to Interchangeable Components." This paper was presented at an S.A.E. meeting early in 1945, and was abstracted in detail in the "Abstracts" section of the March, 1945 issue of PRODUCT ENGINEERING. No definite agreements were reached but further study is being carried on. It was agreed that the situation in regard to the use of first and third angle projection should be cleared up.

METROLOGY. Considerable data had been collected and assembled in usable form by the United States Army Ordnance Department in the document. "Notes on the Use of Circular Dividing Apparatus for Angular and Linear Measurements." The discussion was guided by this and several papers of the National Bureau of Standards and the National Physical Laboratory (Britain). In this subject also, the contracts between the three countries will be maintained.

WILSON COMMITTEE LIMITS COMMERCIAL STANDARDS ACTIVITIES OF GOVERNMENT

IN THE CORRESPONDENCE between Secretary of Commerce Wallace, the Commerce Dept. Policy Committee on Standards headed by Charles E. Wilson of General Electric, and the American Standards Association, the Policy Committee has given assurance that industry will make possible the necessary extensions of the facilities of the A.S.A. to enable it to render all desired services: and the A.S.A. has informed Secretary Wallace and the Policy of its acceptance of the responsibility.

Behind-the-scenes explanation of the three-way correspondence involves the definition of functions of the National Bureau of Standards and of such private standardizing bodies as the American Standards Association.

The June 1, 1945 report of Mr. Wilson's Policy Committee states that the National Bureau of Standards functions should involve "basic research, furnishing of facts, measurements, and technical assistance in the development of adequate testing methods." A further section of the Wilson report emphasized that commercial standards should not be published under government auspices, or at least not under Bureau of Standards auspices.

Wallace's reply to the Wilson report came in the form of a letter to Wilson on February 28. In this letter, he went along with the spirit, if not the letter, of the Wilson report. He did not agree that the commercial standards, developed with the cooperation of industrial advisory groups, should be published by an agency outside of the government. He did, however, agree that such standards should be published by a government group outside of the Bureau of Standards, if a commercial group requested the publishing of such a voluntary standard. To implement this, Wallace will follow the Wilson Committee's recommendation that the divisions of Simplified Trade Practices and Commercial Standards be transferred out of the Bureau of Standards to a "more suitable status elsewhere in the Department." Wallace indicates that the logical place for these divisions is in the Office of Domestic Commerce.

The American Standards Association agreed to go along with Wallace on this issue because it felt that as long as the standards were not being published by the Bureau of Standards, the "sting was taken out of the government's publication of voluntary standards. Many people assume that publication of a standard by the Bureau of Standards is "official" and therefore mandatory. Under the rather nebulous sponsorship of the "Department of Commerce," such publication would not carry nearly as much weight. This is the reason for the show of harmony by all concerned.

WASHINGTON NOTES

Final Compromise

Differences between the Kilgore and Magnuson versions of legislation for federal support of research have finally been ironed out. With the introduction of a new bill, S. 1850, sponsored by both senators (and Senators Pepper, Fulbright, Saltonstall, Thomas of Utah and Johnson of Colorado), the nine-month-old struggle came to an end. All that remains now is to get the "compromise" bill out of committee, passed by the Senate, passed by the House and signed by the President. (This last will be by far the easiest step in the whole process).

Features of the Compromise—Three issues had been the principal bones of contention between the Kilgore idea of a National Science Foundation and the Magnuson version—the latter being supported by Vannevar Bush and the majority of our better-known scientists. Pressure from the White House resulted in the new, "compromise" bill, co-sponsored by Kilgore and Magnuson. The three controversial issues are settled as follows:

1. Administrative Control: The Kilgore plan for a single, presidentially-appointed administrator of the Foundation, aided by a 17-man advisory board of scientists and government officials, is "amended" to create a nine-man board, appointed by the President with the consent of the Senate, and to provide the Tweedledee-Tweedledum choice of an administrator appointed by the President or "nominated" by the presidentially appointed Board.

2. Patents: Kilgore's previous insistence on patenting in the name of the government is "dropped." Here are a few jokers: Patents revert to the private organization doing the research *only* with the consent of the head of the government agency administering the contract. The head of such agency, before allowing an organization to keep a patent must "make a finding that the agency has made every reasonable effort to arrange for the . . . research without entering into a contract containing such provision." In every case, a royalty-free license for the government to use the invention must be granted.

3. Social Sciences: The new bill will provide for financial aid by the federal government in this field. The "Committee Supporting the Bush Report" (see January "Washington Notes") objected specifically to this provision.

Since compromise involves giving something up, Washington wonders whether this flexible noun can be applied to the Kilgore bill.

Atom Policy Wanted

The Special Senate Committee on Atomic Energy, headed by Senator Brien McMahon of Connecticut, has finally gotten down to cases. Out of the mass of bills through which this committee has had to plow, the bill introduced by Senator McMahon, S. 1717, and the May-Johnson bill, S. 1824, have come to the fore as the most comprehensive legislation on atomic energy control.

Washington presents a divided picture on this subject, with the Administration favoring civilian control, as outlined in the McMahon bill, and the War and Navy Departments backing military control, the May-Johnson idea.

McMahon's Framework—In order to free itself from the enormous accumulation of detail, the Senate Atomic Energy Committee decided to concentrate on the McMahon bill, using it as the framework for any legislation eventually reported out. It was evident that liberal addition to, and subtraction from the McMahon bill would be in order. First addition was the Vandenberg amendment, which would create a "military liaison" board, and give it power of appeal to the President if it disapproved civilian decisions.

For those interested in the "skeleton," the following is an outline of the McMahon bill:

I. Control of Atomic Energy (In General)
Bill incorporates specific policy decisions on nature and extent of Government control. Commission's powers are specifically tailored and limited to fit these decisions.

A. Production of Fissionable Materials
Commission to have monopoly of production of fissionable materials. Production in minor quantities incident to research permitted subject to frequent inspection and reports.

B. Fissionable Materials
Exclusive Government ownership of fissionable materials but to be made available for research and licensees (see E) for use in devices.

C. Source Materials
Commission licenses movement of ingredients essential for production of fissionable materials to assure adequate supplies and prevent diversion inconsistent with national welfare. Commission has authority to buy or condemn.

D. By-product Materials
Commission shall distribute for constructive uses, giving preference to research and medical therapy.

E. Atomic Energy Devices (i.e., devices utilizing fissionable materials)
Use not permitted until after report to and opportunity for Congress to legislate on the basis of specific knowledge of utility, practicability, and consideration of economic, political and social implications of marketing such devices. Licensing of atomic energy devices for private use permitted if Congress fails to act in 90 days but such licenses may not extend to the production of fissionable materials.

F. Patents
1. All private patent rights on production processes must be sold to Government (see A).
2. Private patents on devices utilizing fissionable materials permitted subject to compulsory licensing at reasonable royalty rates determined by Commission. (Subject also to E above)

II. Stimulation of Research and Development
Research responsibility and powers of Commission include social, political and broad economic effects of atomic energy developments, as well as military, industrial and scientific research aspects.

A. Independent Research
1. No license or permission from Commission required to do research. Private research must comply with safety regulations, and be subject to inspection.
2. Commission shall give preference to independent research in allocating fissionable materials (See I B).
3. Provides for grants-in-aid, contracts and other forms of assistance.

B. Dissemination of Information
1. *Basic scientific information* is free of restriction.
2. Commission is directed to provide for dissemination of *related technical information* with utmost liberality. Commission by regulation may free such information from all restriction, or, with approval of President, may restrict its dissemination on finding that Espionage Act is applicable.
3. Scientists work under Espionage Act as in peacetime and may, if they desire, obtain clarification of the Espionage Act by action of Commission. Subject only

U. S. Navy Photograph

Degaussing Perfected with Scale Model Ships

Model ships were used by Navy scientists to develop methods of degaussing—neutralizing magnetic fields by introducing counter-magnetic fields within each ship. These systems protected ships and saved American lives from the dreaded German magnetic mine campaign.

The photograph shows a scale model of the light cruiser USS Juneau passing down a magnetic firing track, producing a graph measuring the magnetic field "signature" of the model. The straight portion of the curve at the top indicates that the degaussing equipment is in operation. Disconnected, the variations show where possible explosions of magnetic mines might have occurred.

to regular criminal prosecution under Espionage Act.

C. Government Research
Commission authorized to conduct any type research related to purposes of Act. Takes over Manhattan District Property.

III. INTEGRATION WITH FOREIGN POLICY (IN GENERAL)

Bill emphasizes peacetime uses of atomic energy. Provides affirmatively for dissemination of information to create atmosphere of international confidence. Provides for anticipation of long-range developments through social, political and economic studies. Provides for all-civilian administration of the Act.

A. Bombs and Military Weapons
1. Manufacture permitted only if express approval of President obtained for each quarter. No private or military manufacture permitted.
2. Commission has custody of all bombs and military weapons subject to direction of President.
3. Commission may not conduct research in military uses of atomic energy contrary to international agreement.

B. Preservation of Freedom to Act Internationally (See A re Bombs)
1. Government monopoly of production prevents creation of private interests which might be inconsistent with or deter international agreement.
2. Prohibition of atomic energy devices (see I E) prevents private activities which might be inconsistent with or deter international agreement.

C. International Control of Fissionable Materials
1. Private export or import of fissionable materials forbidden.
2. Private participation in production of fissionable materials in another country forbidden.

IV. ORGANIZATION

A. Structure
Bill creates five-man Commission, all members serving full-time. Four subordinate directors to have functions as assigned by Commission. Express provisions against conflict of interests.

B. Appointment and Removal
1. Members of Commission and four Directors appointed by President.
2. All must be civilians.
3. All serve at pleasure of President.

Aircraft Production Techniques Of U. S. and Germany Studied

STUDY OF GERMAN AIRCRAFT production techniques by officers of the Production Division of the Navy's Bureau of Aeronautics indicates that new products could be made and designs could be changed quickly. However, the Naval officers are of the opinion that the American aircraft industry has little, if anything, to learn from the Germans as regards details of production.

The findings of the officers are based on visits to 15 German aircraft plants, including factories producing airframes, instruments, and aircraft engines.

In some respects, U. S. aircraft companies have made widespread use of techniques considered superior to those used by the Germans. Examples of U. S. superiority cited in the report are: control of machined surface finishes, sheet metal work in general, plant layout, internal transportation, use of work-handling machinery, factory organization, working conditions favorable to a sustained high rate of individual effort, and the avoidance insofar as possible of extreme degrees of regimentation and use of forced labor.

German methods are considered by the investigators to be outstanding in the following respects:

1. Development of unconventional products was encouraged.

2. German aircraft produced for war purposes not only performed well, but also was designed for easy production with the means at hand.

German aircraft producers, used as direct labor large number of skilled machinists, products of the German apprentice system, who would be classified as toolmakers in the United States. In contrast to this, elaborate methods and designs of special tooling in the United States permitted high-quality, high-rate production by unskilled workers.

Also, the German aircraft industry was dispersed. Several sources were provided for both the manufacture of current aircraft designs, and for compound parts. In the United States, more designs were in production, but there were critical concentrations of many important components.

"Huff-Duff"—High-Frequency Radio Direction Finder

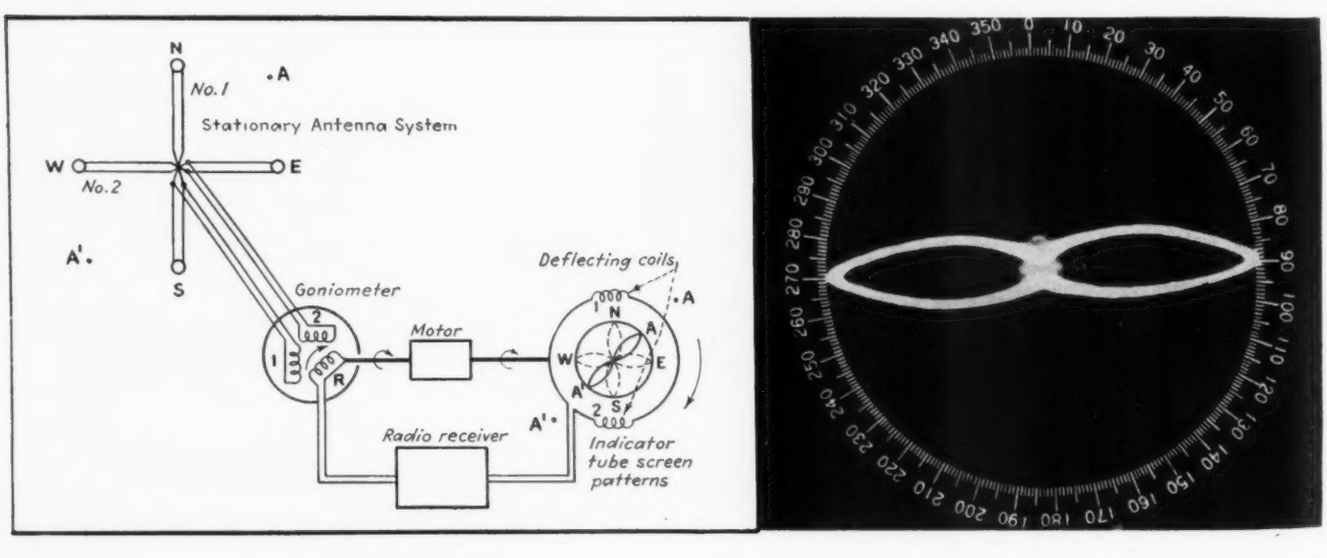
RECENTLY REVEALED were details of the high-frequency direction-finder, known as HF/DF or "Huff-Duff," which was developed for the Navy by the Federal Telephone and Radio Corporation. By means of this equipment, the direction from which a radio beam is coming can be instantaneously determined. To find the distance, two or more such installations are required.

In peace, DF systems are used to determine the positions of ships or aircraft on request and notify them of their location; in war these systems are used to locate the enemy. An additional requirement of military apparatus is that it must indicate direction instantly, because enemy transmissions are apt to be short as possible. Credit is given to the HF/DF for greatly lessening the submarine menace in the Atlantic during the war.

Accompanying drawing illustrates operation of a typical HF/DF installation. Stationary antenna system consists of an east-west antenna, a north-south antenna and a center antenna. Impulses received from the sending station are carried to the goniometer, or indicating assembly.

The goniometer, a device that eliminates the necessity for a revolving antenna, consists basically of a stator and a motor-driven rotor. The stator holds specially designed primary coils wound at critical angles, connected to the two direction antennas. The rotor carries corresponding secondary coils connected to the deflection plates of the cathode-ray oscilloscope, or indicator tube.

The rotor coil, driven by the motor, stops rotating when the received signal is strongest. The pattern seen on the oscilloscope screen is loop-shaped, as shown in the photograph. In order to know which end of the loop is the correct direction, a button is pressed which connects in the "center" antenna, a special circuit of all directions. This acts to momentarily "fold up" the pattern, indicating end of the loop that shows the true direction.



RESEARCH NOTES

Franklin Institute Reorganizes Industrial Research Laboratories

To serve industry in the solution of problems where the application of pure science to practical engineering is involved, reorganization of the Franklin Institute Research Laboratories was announced recently by Dr. Henry Butler Allen, secretary and director of the Institute Headquarters will be at the Franklin Institute, 20th Street and the Parkway, Philadelphia.

The idea for the Research Laboratories is an outgrowth of the work done by the Institute during the war for Army Ordnance, the Navy and the Office of Scientific Research and Development. In order to properly deal with problems in design of more powerful guns, sights and other important Ordnance equipment, the Institute's laboratories expanded to an unprecedented extent. They now consist of many individual laboratories, shops, offices and drafting rooms, and are staffed with about 150 scientists and engineers. The importance and success of the Institute's wartime research projects were recognized by the Army's Ordnance Distinguished Service Award in September, 1944, and the Navy's Ordnance Development Award in December, 1945. The laboratories are still engaged on projects for the armed services, but are being expanded to handle a peacetime program of research. In addition to the research facilities at the Institute's headquarters, two separate divisions of the Institute are devoted to research: The Bartol Foundation in Swarthmore and the Biochemical Research Foundation at Newark, Delaware.

Among the sponsors of the idea for the Research Laboratories were Dr. Allen and Dr. Rupen Eksergian, chief consulting engineer for the Edward G. Budd Manufacturing Company and a member of Division One, National Defense Research Committee on Ballistic Control and the Design of High Velocity Guns. Dr. Eksergian is winner of the Franklin Institute Levy Medal for his paper, "On the Reaction of Fluids and Fluid Jets," and is co-founder of the Applied Mechanics Division of the American Society of Mechanical Engineers.

Work of the Research Laboratories will primarily be concerned with fundamental research and studies in the application of physical sciences. Leadership will be obtained through a strong staff well qualified in basic engineering science, physics and chemistry. Beyond this staff, it is proposed to include outstanding consultants who will devote some of their time to the work of the Laboratory.

Lt. Col. Charles H. Greenall has been appointed executive director of the Laboratories. Col. Greenall, a mechanical engineer specializing in materials development, was formerly supervisor in charge of metallic materials at the Bell Telephone Laboratories. In 1940, he was called to serve as consultant to the director of research at Frankford Arsenal. In February, 1942, he became executive officer and in October of the same year he was named director and officer in charge, in which capacity he served until his appointment at the Institute.

Acting as senior consultants to Dr. Allen will be Dr. Eksergian and Dr. W. F. G. Swann. Dr. Swann, director of the Bartol Research Foundation of the Franklin Institute, which deals with fundamental physical research, was formerly on the faculty of Sheffield University in England, chief physicist of the Department of Terrestrial Magnetism at the Carnegie Institution, in Washington, D. C., and director of the Sloane Laboratory of Yale University.

Further administrative personnel will be Dr. Nicol H. Smith, director of the division of chemical engineering; Ralph H. McClarren, division of electronics and instruments; and George S. Hoell, division of mechanical engineering. Dr. Smith and Dr. McClarren are associate directors of the Franklin Institute Museum. Mr. Hoell served during the war as ordnance engineer at the Institute, in the employ of Army Ordnance, later becoming chief engineer of the Artillery development Suboffice located at the Institute.

Former Under Secretary of the Navy Artemus L. Gates presents Distinguished Service Medal to Rear Admiral Luis De Florez, U.S.N.R., for his services as director, Special Services Division, Bureau of Aeronautics, and assistant chief of the Navy's Office of Research and Inventions.

Westinghouse Resumes Scientific Research Fellowships

Rounding out the transition from war to peacetime industrial research the Westinghouse Electric Corporation has announced resumption of fellowships to young scientists for work on pure scientific research.

Under the plan, young scientists having training equivalent to a doctor's degree from a recognized university, are chosen from all sections of the country to carry out research which they themselves outline and initiate. They may be reappointed for a second year if mutually desirable. The fellowship has a value of $3300 a year.

Considered especially important this year are investigations of the fundamentals of ferromagnetism and the properties of semiconductors. Problems in the fields of nuclear physics, conduction of electricity in gases, dielectrics, thermionics, applied mechanics and chemical physics are also appropriate.

All applications will be considered, however, whether or not projects outlined cover these fields.

Heat-Stable Ceramic Coatings Developed by Bureau of Standards

CERAMIC COATINGS that stay put under extreme heat, developed by the National Bureau of Standards primarily to protect the exhaust systems of military internal combustion engines, promise to have important peacetime applications.

Exhaustion experiments demonstrated that the addition of certain quantities of calcined aluminum oxide and a slight modification of conventional practice produced an enamel coating that would protect conventional steel exhaust stacks from corrosion.

An application of great military importance was in the coating of the exhaust systems of

MEETINGS

Society of the Plastics Industry—First National Plastics Exposition, April 22-27, Grand Central Palace, New York City.

Products of Tomorrow Exposition—April 27-May 19, Chicago Coliseum, Chicago.

American Ceramic Society—Annual meeting, April 28-May 1, Hotel Statler, Buffalo, New York.

National Association of Corrosion Engineers—Annual meeting, May 7-9, President Hotel, Kansas City, Mo.

American Foundrymen's Association—Annual meeting and Foundry Show, May 6-10, Cleveland Auditorium, Cleveland.

Chamber of Commerce of the United States—Annual meeting, April 30-May 2, Atlantic City, N. J.

National Aircraft Standards Committee—National meeting, May 6-7, Hotel Lexington, New York.

Mid-America Exposition—Industrial exposition, May 23-June 2, Public Hall, Cleveland 14, Ohio.

RECENTLY ELECTED SOCIETY OFFICERS

Resistance Welder Manufacturers Association, 850 Euclid Ave., Cleveland 14, Ohio. President—H. B. Warren, Electric Welding Co.; Vice President—G. N. Gieger, S-M-S Corp.; Executive Secretary—George A. Fernley, Philadelphia, Pa.; Secretary-Treasurer—H. R. Rinehard, Philadelphia, Pa.

National Aircraft Standards Committee, 610 Shoreham Building, Washington 5, D. C. Chairman—G. T. Waite, Consolidated Vultee Aircraft Corp.; Western Division Chairman—L. J. Catlin, Douglas Aircraft; Eastern Division Chairman—J. F. Hammond, Boeing Airplane Co.; Secretary—V. G. Mellquist, Aircraft Industries Assn.

Society for Experimental Stress Analysis, Cambridge 39, Mass. President—C. Lipson, Chrysler Corp.; Vice President—R. D. Mindlin, Columbia University; Secretary-Treasurer—W. M. Murray, Massachusetts Institute of Technology.

Technical Association of the Pulp and Paper Industry, 122 E. 42nd St., New York 17, N. Y. President—Gunnar W. E. Nicholson, Union Bag & Paper Corp.; Vice President—Worthen E. Brown, Pejepscot Paper Co.; Secretary-Treasurer—R. G. MacDonald.

Automobile Manufacturers Association, New Center Bldg., Detroit, Mich. President—George W. Mason, Nash-Kelvinator Corp.; Vice-President—Paul G. Hoffman, Studebaker Corp.; Secretary—Albert Bradley, General Motors Corporation.

army "Ducks" for which no priority on stainless steel had been provided. In the Pacific theater especially it was found that the exhaust systems of the Ducks corroded quickly and seriously. When exhaust pipes were given the ceramic coating inside and outside the corrosion problem was solved.

To insure best results the new ceramic enamel must be applied in this coats—not more than 2 to 3 thousandths of an inch on the exhaust stacks of air-craft engines and Ducks. It has a dull finish such as found in conventional porcelain enamels and is applied at a temperature of 1600 deg. F., only a little higher than that ordinarily used.

A section of exhaust stack that had been subjected to repeated applications of great heat at a given point showed no break whatever in the new coating. Even when the metal itself bulged slightly at the point where the heat was, no damage resulted.

Automobile manufacturers are among those indicating an active interest in the use of these coatings on the exhaust systems of cars and trucks. Several stove manufacturers are showing keen interest in applications of the new coatings to certain parts of their products, including the inner liners of oil space heaters. Another application under consideration is the coating of burners on gas ranges, the supports on which the pots rest and other points where high-temperature resistance is important.

A promising industrial use is as coatings for heating-furnace tools. These tools are repeatedly subjected to very high temperatures as they hold in place articles undergoing heat treatment.

Thinner coatings and other benefits, it is believed, would take care of the cost factor.

First "Two Stage" Turbo Supercharger

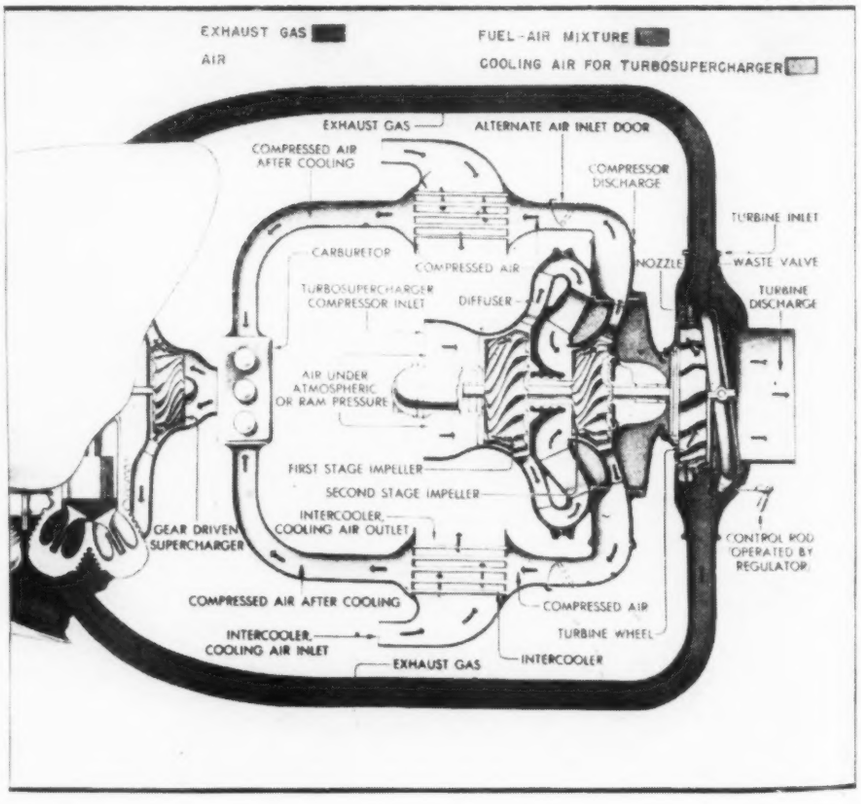
FIRST "TWO-STAGE" TURBO-SUPERCHARGER in the world has been developed for use in Navy Corsair planes, making possible efficient operation at altitudes above 40,000 feet, which is 10,000 feet higher than the normal service ceiling for this standard Navy fighter.

The supercharger, which is used in conjunction with the R-2800-C Pratt & Whitney engine, was developed under Navy Bureau of Aeronautics contract by the Turbo Engineering Corporation of Trenton, New Jersey. It is being installed in one complete squadron of Corsairs.

The "two-stage" turbo-supercharger differs from previous models in that the air coming into it passes through two stages of compression, rather than one. Since the R-2800-C engine incorporates one engine-driven supercharger in addition to the turbo, the air is subjected to three actual stages of compression, making possible operation in extremely rarified atmosphere. The drawing shows the air and exhaust gas baths in a turbo-supercharger installation.

Among the features of the new turbo-supercharger are a highly efficient compressor and a turbine wheel capable of withstanding the high temperatures of engine exhaust, in order to permit a close-couple installation, light weight cowling. Thus the

U. S. Navy



drag associated with such devices is reduced and use is made of the propulsive jet effect of the exhaust gases.

The turbo-supercharger, in addition to its two-stage mixed flow compressor, also incorporated internal air cooling. The mixed flow compressor is a combination of an axial flow and centrifugal flow compressor, and has proved highly efficient. The new supercharger enables the R-2800 engine to develop sea level military rated power at 40,000 feet altitude.

The new device was not used in World War II combat although it would have been available had the enemy suddenly begun to utilize a super-high-altitude bomber.

Technical missions to Germany and Japan have found turbo-superchargers and other gas turbines in both countries, but none of the new "two-stage" variety.

DISCUSSIONS AND COMMENTS FROM READERS

Comment on Properties Of Gas Welds Article

To the Editor:

We have several comments on the article, "Properties of Gas Welds in Three Alloys of Sheet Magnesium", by Mr. W. H. Jones which appeared in the September issue of Product Engineering.

Our comments are intended primarily to point out some errors in the data and to add something to the discussion:

1. The strengths of the sheet alloys and welds were listed in Table I in lb. per sq. in., whereas the actual values were in lb. per lineal inch.

2. The Mh sheet strength values as listed in Table I were calculated and found to be 29,000 lb. per sq. in. These were unusually low for Mh, typical values being 37,000 lb. per sq. in. with minimum of 32,000 lb. per sq. in. We wonder if the sheet had been heated or whether there is some other explanation for this.

3. According to the text, the flanged joints had a $\frac{1}{8}$ in. radius, which would amount to a 1½-thickness bend on the 0.040 in. radius of 7 times the thickness, at 400 deg. F. which is the maximum temperature to which the material can be heated without loss of properties. In order to obtain such a sharp bend radius as given in this article the material must have been heated well over 400 deg. F., in which case the material would be converted to the annealed state.

Also, Table I indicates that Ma strips were used in flanged joints and we wonder if that was merely a tabulating error.

4. The statement that heat treatment of welds at temperatures of 450 to 500 deg. F. results in lower tensile strength and deterioration of weld structure is not in agreement with our results. We have found no reduction in weld strengths after heat treatments up to 500 deg. F. for time intervals of one hour on M or J-1 sheet material. We have no similar data on gas welded FS-1, but our guess would be that the weld strengths would not be affected appreciably by heat treatment up to 500 deg. F.

5. The statement in the first paragraph about the undesirability of FS-1 welds because of low resistance to corrosion and hot shortness does not appear to be entirely justified and needs further discussion.

The lower resistance to corrosion of FS-1 welds in comparison with M welds in accelerated salt spray or immersion conditions. Seacoast exposure tests, at Wilmington, N. Carolina over a period of several years have shown that FS-1 welds stood up as well as M welds. The apparent difference in corrosion of the welds is observed only in electrolytic solutions and is caused by the metallurgical changes occurring as a result of welding. Under even severe coastal atmospheric exposure, there is no difference between M and FS-1 welds, and no preferential attack adjacent to the weld as occurs in the accelerated tests.

The FS-1 sheet is more difficult to weld than either M or J-1 because of its greater weld cracking tendency. Weld cracking can be greatly reduced by the substitution of J-1 for FS-1 welding rod and by the use of helium or argon arc welding instead of the gas welding process. As a result, any welding on FS-1 is usually done with the helium or argon arc process. Many complicated structures are now being welded with the FS-1 alloy.

—Paul Klain
Metallurgical Department
The Dow Chemical Company

To the Editor:

Answering the comments made by Mr. Klain, he has made some pertinent comments which I will discuss in the order given. First, however, a review of the background for the tests on which the article was based will serve to clarify the results presented.

At the time the tests were conducted very little specific information was available on weld strengths, weldability, etc. It was necessary to obtain preliminary data in a relatively short time in order to proceed with designs. In addition, the selection of sheet stock was limited in that both hard nesses were not available in all gages. Therefore, some of the tests are somewhat "rough" in scope as will be explained in the discussion.

On the basis of the above, the following comments are made:

1. The table as published is in error since the original report shows these values as ultimate tensile strength in pounds.

2. These strips had sheared edges and the width measured with a scale rather than a micrometer. This would account for some of the difference in strength values.

3. The bends were made at approximately 600 deg. F. The only precaution taken was to prevent overheating.

In making the flanged welds, some filler material was added from the strips of sheet. At the time these particular welds were made the supply of the Dow filler rods had not arrived.

4. The results of the heat treatment, we have since realized, may be questionable. However, they did indicate that there was no contribution to the weld quality and therefore this treatment was not recommended for production parts.

5. (a) The "M" alloy for gas welding is acceptable for a broader range of design and is less susceptidle to cracking where there is apt to be any appreciable strain on the weld during the heating and cooling cycle.

(b) The electrolytic test is conceded to be a very severe one, too much so to duplicate even the most severe conditions encountered in actual service. It has, however, been adopted as a standard by many concerns. The testing done at Wilmington does give a true picture of the performance —something which cannot be duplicated in "short time" tests.

(c) The advantages of the helium arc process over the gas welding process are known. However, at the time these tests were conducted, the helium arc equipment was not available.

Some welds were made using the J-1 filler alloy which were very satisfactory but time did not permit going into further detail on this procedure. The value of the above procedure is now known.

The approved alloys for production did not include the J-1. Therefore the subject tests were made only on the "M", FS, and 52S alloys.

I appreciate the interest Mr. Klain has shown in making comments on the published article and believe he has added considerable useful information.—W. H. Jones

Wants Plastic Finish For Die Castings

To the Editor:

We have read with interest the article on plastic resin coatings in the January issue of Product Engineering. We manufacture a paint spray gun using zinc base die castings on the two major parts of the spray gun. At the present time, our method of finishing these parts is polish and nickleplating. If possible we would like to find a plastic resin coating that we could use on these parts in place of the nickle plating.

We recently examined a product manufactured of aluminum die castings which appeared to have a plastic finish. The unusual part of this product was that the coating appeared to have been buffed after it was sprayed and probably after it was baked if baking was a part of the operation. We would appreciate your advising us of any such finishing material now available.

—E. H. Marti
W. R. Brown Corp.

Analysis of Servomechanisms For Instrument and Power Drives

G. S. PERKINS
Engineering Department, Paramount Pictures, Inc.

Analyzing both power-drive gear trains and instrument-gear trains of servomechanisms, the author explains the influences of moments of inertia, friction and backlash and states the limits in these factors for satisfactory performance and damping. Two examples of the calculation of inertia effects are given.

A SERVOMECHANISM is generally defined as a power amplifying device in which the amplifier element driving the output is actuated by the difference between the input to the servo and its output. Fig. 1 is a diagrammatic illustration of a continuous control servomechanism.

The purpose of this discussion is to set forth the problems met in the mechanical design of a servo-gear train and to give some generalizations as to how they may be solved. No consideration is given to the design of the servoamplifier. The complete servomechanism consists of five parts, namely, the data source, data receiver, amplifier, motor, and the gear train.

The input to the servo is usually an angular displacement of a shaft which is translated into electrical information by means of a synchronous generator unit. This information is in turn fed to the synchro receiver (control transformer) whose output is a voltage, usually referred to as the servo error voltage, which is fed into the servoamplifier. The amplifier output powers the motor and drives it until the error voltage is reduced to zero. This occurs when the synchronous receiver is in mechanical phase with the synchronous generator. From Fig. 1 it can be seen that the control transformer (data receiver) is mechanically linked to the motor by the gear train. An ideal servomechanism is one in which the input and output shafts are in exact phase at all instants of time. Although the ideal servo is never obtained in practice, ideal performance represents the goal toward which the design of actual servomechanisms is directed.

The actual servomechanism when compared to the ideal suffers from two principal defects—oscillation and lag. Oscillation is the periodic deviation of output from input. Lag is an overage or unidirectional deviation. Both sources of error are always present in some degree, and the function of design is to reduce these errors to negligible magnitudes. The following discussion is wholly concerned with the gear train.

Servo gear trains may be placed in two general classes: instrument drives and power drives. In both classes accurate gears, at least meeting A.G.M.A. Precision Class 1 Specifications, correctly assembled, will serve to help minimize both the oscillation and lag errors. Instrument drive gear trains transmit loads whose gear strength requirements can be met by fine pitch gears. Fine pitch gears, as defined by the American Gear Manufacturer's Association, are gears of 20 diametral pitch and finer. Power-drive servo gear trains require gears stronger than obtainable with 20 diametral pitch.

To determine a ratio for the gear train, the optimum speed of the motor is divided by the desired output speed.

$$\text{Gear ratio} = \frac{\text{Optimum speed of motor}}{\text{Output speed}} \quad (1)$$

The optimum speed is usually about 2/3 the full speed of the motor. This allows a small surplus of speed, Fig. 2, which is available if needed, and causes the servo output torque to be fairly constant throughout the speed range.

Power drive servo trains will be considered

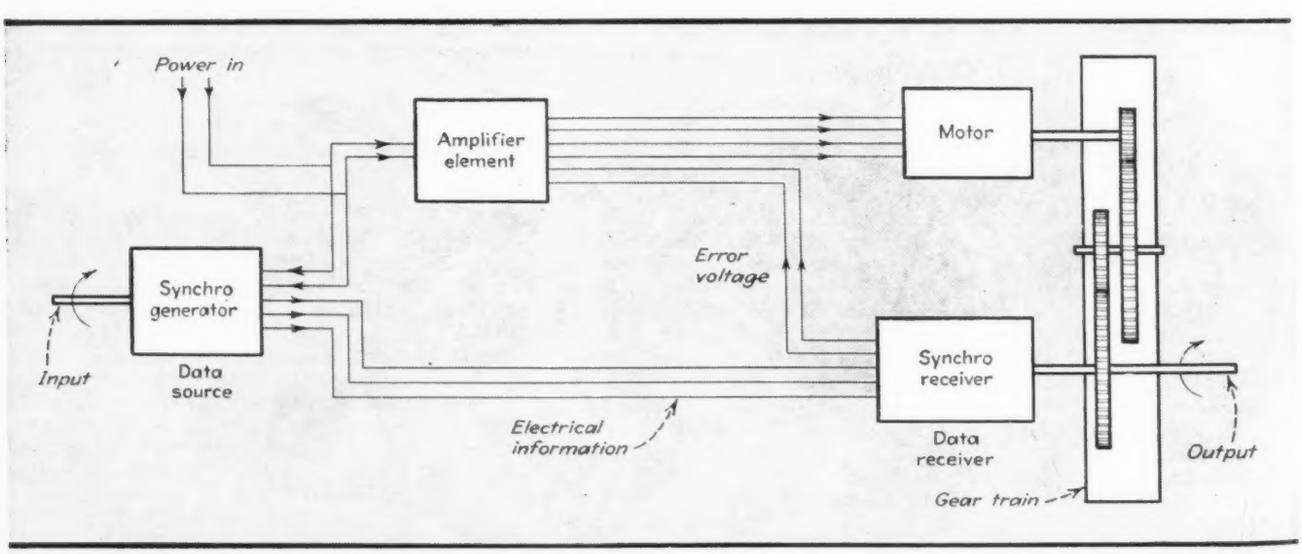


Fig. 1—Five parts of a continuous control servomechanism—data source, data receiver, amplifier, motor and gear train.

first. A characteristic of the continuous control servomechanism is instant reversal of the gear train under full load in response to the input signal. This characteristic subjects the power drive gears to the hazard of impact damage. The errors of oscillation and lag are always present in some degree. Sloppy gearing will allow greater oscillation and lag errors, which might in turn increase the impact load to the point of failure.

Gears for heavy power servo trains should be of precision quality and made in conformity with the closest tolerances practicable for the size of the gear. The gear-train assembly can well have an adjustable center distance on the last gear mesh. This will serve to eliminate backlash in the region of greatest tooth pressure, thereby greatly reducing the possibility of damage from impact.

Table I—Tolerances on Gears for Use in Instrument-Gear Trains

Dimension or surface	Tolerance, in.	Remarks
Outside diameter	+ 0.000 − 0.001	
Concentricity of O.D. with bore	0.001	Total indicator reading
Bore diameter	+ 0.0000 − 0.0002	Hold to small side of tolerance
Taper of bore	0.0001 per in. of length not to exceed 0.0002 regardless of length	Must not be bell mouthed
Finish of bore	A.S.A. Class four fit	Must be smooth
Concavity of transverse face or hub of gear	0.0002 per in. not to exceed 0.0015 total	Mounting surface
Convexity of transverse face of gear	0.0000	None allowed
Lateral runout	0.00025 at 1.000 in. radius not to exceed 0.001 at 3 1/2 in. radius	Total indicator reading
Pitch diameter runout	0.001	Total indicator reading

Instrument Gear Trains

A separate parallel gear train of equal ratio should be used to drive the synchronous unit receiver (control transformer), Fig. 1. This controller gear train, powered from the servomotor, may be made of instrument precision gears. The problems of oscillation and lag are present in instrument servo gear trains. Impact is not a problem because instrument-gear trains can be assembled without measurable backlash. Reduction of friction and inertia on the other hand are

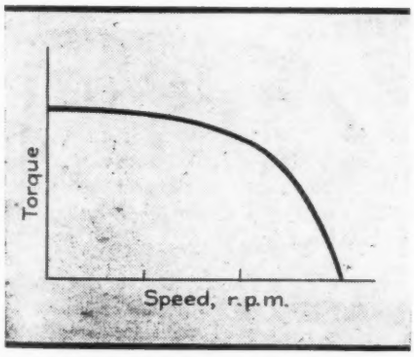


Fig. 2—A typical torque-speed curve of a servomotor.

of paramount importance. They have a direct effect on the lag angle.

Friction in the instrument servo-gear train should be as little as possible. Accurate and careful workmanship in the assembly of the gearing is probably the best safeguard against friction. Bearings can be selected for smoothness, and should be cleaned and carefully lubricated. The first pinion is usually mounted in cantilever fashion directly on the motor shaft. This will eliminate shaft or bearing friction for the first or high speed gear. Special care can be taken to be sure that all of the gears mesh smoothly. Allowable static torque of an instrument servo gear train, measured at the motor shaft, should be less than 1/8 of the rated torque of the motor. If this rule is followed, the lag error due to friction will not be serious.

Moment of inertia of the instrument servo gear train is important because it usually represents a load on the motor greater in proportion than the load the servo is driving. Lag error during acceleration is a function of inertia. Most of the moment of inertia of the gear train is found in the gear driven by the motor pinion. A lightweight material is recommended for that gear. This is especially necessary if the servo system is to be mechanically damped. Mechanically damped systems require that the total moment of inertia transmitted to the motor be less than 3/4 of the inertia of the motor rotor. The expression for moment of inertia in weight units of servo gears is usually written as follows:

$$I = \frac{\pi r^4 l d}{2} \qquad (2)$$

where r is the radius at pitch line of gear, l is the length of cylinder (face width of gear), and d is the weight per unit volume of gear material. Equation (2) gives the moment of inertia in units of weight times distance squared.

When power or acceleration calculations are performed, the moment of inertia is expressed in mass units.

$$I_m = \frac{\text{Weight (distance)}^2}{g} \qquad (3)$$

The allowable inertia differs with each servo application. Three factors for determing the allowable inertia are as follows:

1. Performance data in terms of the required acceleration rate, expressed in radians per sec.

2. Moment of inertia of the servo driven load referred to the motor shaft; this varies inversely as the square of the gear ratio between the motor and the load so that

$$\text{Inertia of load at motor shaft} = \frac{\text{Inertia of load}}{\text{gear ratio}^2} + \text{Inertia of motor rotor} \qquad (4)$$

3. Torque available from the motor, expressed in weight distance units.

This is obtained from the torque vs. speed curves on the motor.

Having these data and the moment of inertia of the proposed gear train, calculation of acceleration rate is a simple matter. The rate is called the "available acceleration rate' 'in the following relation:

$$\frac{\text{Available acceleration rate}}{\text{Required acceleration rate}} = \text{Acceleration ratio} \qquad (5)$$

The available acceleration ratio divided by the required acceleration rate defines the acceleration ratio. If the acceleration ratio is two or more, experience shows that the moment of inertia of the proposed gear train is well within satisfactory limits and the servo-gear train is in a good operating range to function with a minimum of lag error because of inertia. This rule is applicable to both power drive and instrument servo gear trains. A mechanically damped servo system should have an acceleration factor of 150 or more.

Oscillation can be minimized in instrument-servo-gear trains by eliminating backlash. Precision gears, carefully assembled, will assure the absence of measurable backlash. Table I lists the specifications and requirements of fine pitch precision instrument gears that have given satisfactory performance in servomechanisms.

The gear housing for a servo-gear train must be rigid. Bearing bores should be such that the bearings can be pressed in by hand. Tightness in bearing fits causes binding, which adds to the friction. Tolerance limits for boring the center distances for assembling precision instrument gearing is the theoretical center distance plus 0.0005 in. and minus zero.

Two examples will illustrate the inertia calculations of actual servo-gear trains. Both gear trains are of the instrument drive type. The first example is a gear train for a mechanically damped servo system.

EXAMPLE 1: The following servo gear train data are given: the total gear ratio of motor to load is 50 to 1; the angular velocity of

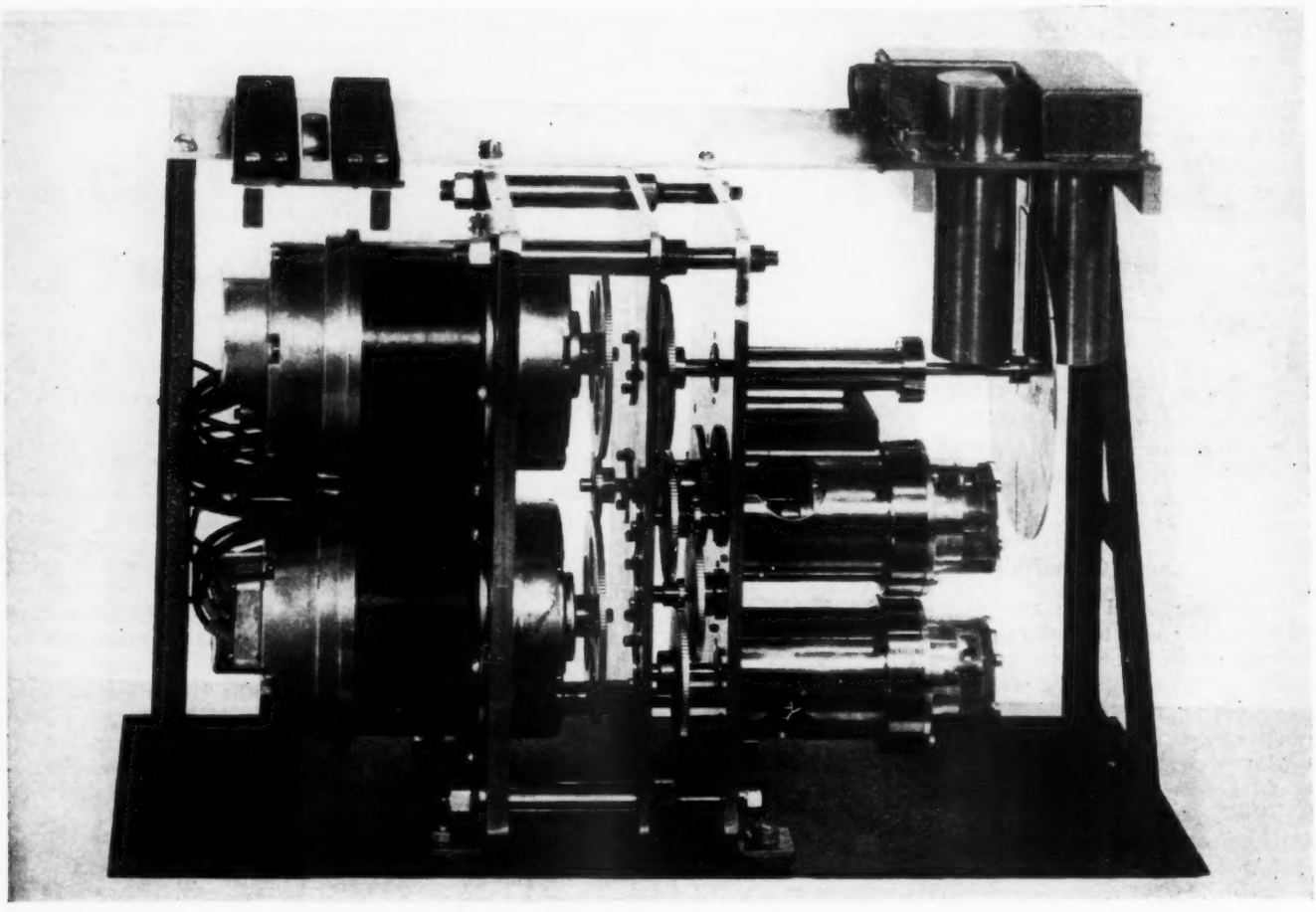


Fig. 3—A typical instrument-servo-gear train and synchro-receiver.

output shaft is 18 rpm.; the time of acceleration of output shaft is t equals 2 sec; the torque available from motor is 2.5 oz.-in; the moment of inertia of the servo driven load at output shaft is 47.8 oz.-in.^{2} weight units; and the moment of inertia of motor rotor is 0.082 oz.-in.^{2} weight units.

The gear train has two stages of reduction such that the first reduction is 5 to 1 and the second is 10 to 1. The first gear is aluminum alloy having a density of 1.57 oz. per cu. in., a face width of 0.125 in., and a pitch diameter of 1.875 in. The second gear is bronze alloy having a density of 5.08 oz. per cu. in., a face width of 0.188 in. and a pitch diameter of 3.333 inches.

The acceleration ratio, Equation (5), is to be found. The required acceleration rate of the motor is

$$d_r = 50 \times \frac{2\pi \times 18}{60 \times 2} = 15\pi \text{ radians per sec. per sec.} \quad (6)$$

This is the magnitude of the denominator of Equation (5). The numerator of Equation (5) is a summation of the moments of inertia of the parts of the system referred to the motor shaft. The parts of the system are the motor rotor, the servo-driven load and the gears between them.

The moment of inertia of the motor rotor (given) is 0.082 oz.-in.^{2} weight units. The moment of inertia of the servo driven load is 47.8 oz.-in.^{2} weight units, which means 47.8/2,500 = 0.019 oz.-in.^{2} weight units referred to the motor shaft.

By substitution in Equation (2) the moment of inertia of the first gear is 0.238 oz.-in.^{2} weight units. This becomes 0.238/25 or 0.009 oz.-in.^{2} weight units at the motor shaft. Similarly the moment of inertia of the second gear is 11.585 oz.-in.^{2} weight units. This becomes 11.585/2,500 or 0.005 oz.-in.^{2} weight units at the motor shaft.

In general, the moment of inertia of pinions and gears beyond the third reduction is small and may be neglected. Thus the total moment of inertia is the sum of 0.082, 0.019, 0.009 and 0.005 or 0.115 oz.-in.^{2} weight units. If this is changed to mass units, Equation (3) becomes

$$I_m = 0.115/386.4 \text{ oz.-in.}^2 \text{ mass units.}$$

The available acceleration rate is the torque divided by the mass units, or

$$\frac{2.5 \times 386.4}{0.115} = 8{,}400 \text{ radians per sec. per sec.} \quad (8)$$

Substituting the values from Equations (6) and (8) into Equation (5) gives

$$\text{Acceleration ratio} = 8{,}400/15\pi = 178. \quad (9)$$

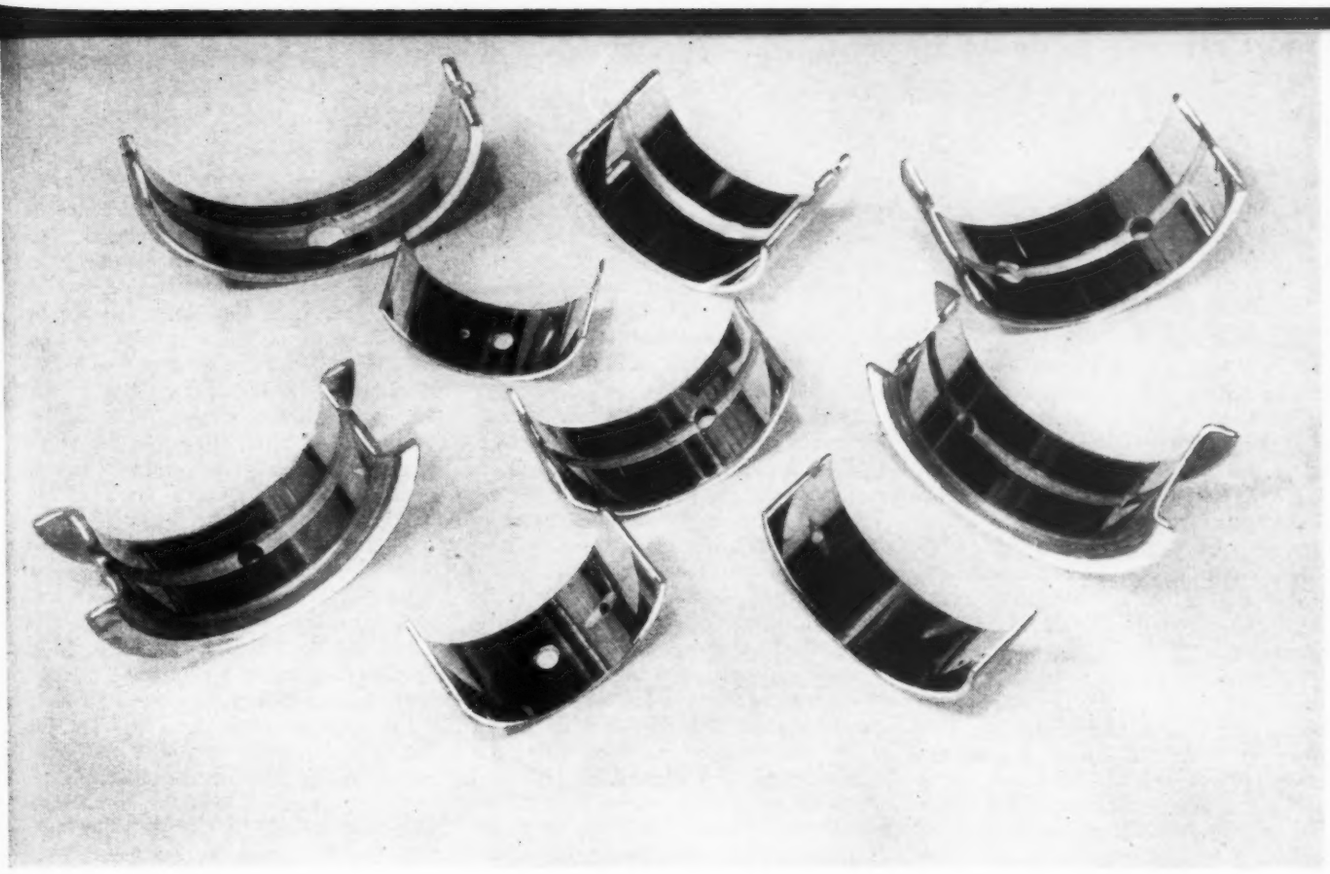
The acceleration factor exceeds 150. This indicates the inertia of the gear train to be within limits and that a good design has been achieved.

EXAMPLE 2. In the servomechanism shown in Fig. 3 the total gear ratio of motor to load is 160 to 1; the angular velocity of the output shaft is 18 rpm.; the time of acceleration is 2 sec.; and the torque available from the motor shaft is 2.5 oz.-in. The acceleration ratio is desired.

By the method illustrated in Example 1 the total moment of inertia of the systems was determined as 1.65 oz.-in.^{2} weight units at the motor shaft. This represents 1.65/386.4 oz.-in.^{2} mass units.

The available acceleration rate is 2.5x 386.4/1.65 or 585 radians per sec. Substituting the values in Equation (5) gives 585/201 or 2.9 as the acceleration ratio. Since the acceleration factor exceeds two, a satisfactory design is indicated.

EDITOR'S NOTE: Based on work done for the Office of Scientific Research and Development under contract OEMsr-262 with the Radiation Laboratory, Massachusetts Institute of Technology.



Durex-100 Engine Bearings

Material Characteristics and Design Data

J. A. LIGNIAN
Bearing Engineer, Moraine Products Division, General Motors Corporation

Characteristics and construction of the Durex-100 engine bearing are described. The article also discusses design of bearings, with particular reference to the use of this material, and methods of obtaining crush stresses in bearing shells. Sample calculations illustrate the method.

IN DESIGN AND CONSTRUCTION the Durex-100 Bearing is a radical departure from standard types of steel-backed precision bearings. It is essentially a steel-backed lead-base babbitt bearing, incorporating the use of a metallic spongelike structure, or matrix, into which the babbitt is cast. This babbitt, developed specifically for use in this bearing, is a corrosion-resistant high-lead alloy, General Motors specification 4167 M, containing 3 percent antimony, 4 percent tin and the balance lead.

The matrix is formed on SAE 1010 steel in a continuous strip process by sintering pure metallic copper and nickel powder to the strip. These powders are mechanically mixed in the proportions of 60 percent copper and 40 percent nickel, by weight. During the sintering process the copper melts, alloying with the nickel and brazing the structure to the steel. The strip thickness is held to close limits by subsequently passing the strip through sizing rolls.

Following the rolling, the strip is passed continuously through a special vacuum impregnating and casting machine, Fig. 1, that fills all the pores of the matrix with babbitt and leaving a sufficient excess layer of babbitt, Fig. 2, for final machining of the bearing to precision finished dimensions.

All bearing blanks, including flanged bearings, are blanked from the strip crosswise. In circle-forming, the half-bearings are coined on the split lines to create a flat back. The coining operation thickens the steel back near the split lines. To maintain a constant 0.003 in. maximum overlay of babbitt over the rolled matrix surface in the finished bearing it is necessary to have a contoured matrix. This contoured matrix surface is carried through from the first operation of applying the powder on the strip to the sizing rolls. Contour changes somewhat with different bearing diameters and wall thicknesses. Following the circle-form oper-

ation, the bearing halves are machined to finished precision interchangeable bearings in a conventional manner.

Material Characteristics

The combination of this high-lead base babbitt alloy with the matrix produces a bearing material having advantages not obtainable in other types of material. A higher bond strength of the babbitt is obtained by use of the matrix, which is brazed to the steel. The babbitt is not only bonded metallurgically to the matrix, but the porous nature of the matrix results in a strong interlocking mechanical bond. The actual bond area per sq. in. of bearing surface is far greater than where the babbitt is bonded to a flat surface.

The majority of white metal bearing failures can be traced directly to failure of the bearing lining from fatigue cracking, that usually starts at the surface and extends radially, approaching the bond line of the babbitt and backing material. These cracks then progress parallel to the bond line until small areas become separated from the lining. Hydraulic pressure forces these small pieces against the crank journal, fracturing the oil film with resultant metal to metal contact, shown in Fig. 3. Local heat is developed and eventually these pieces melt and leave holes in the bearing. This process continues until either oil pressure is lost through an open passageway from an oil groove to the end of the bearing, or the effective bearing area is so reduced that it will no longer maintain an oil film, and the entire bearing lining fails.

Bearing materials will show fatigue cracking under continual deformation, but with Durex-100, the valleys and plateaus of the matrix breaks up the progression of the fatigue cracks, thus prolonging the time required for the fatigue cracks to isolate small pieces. However, even if pieces have become loosened from the matrix, the interlocking of the matrix, Fig. 4, prevents the pieces being lifted by hydraulic pressure and the bearing continues to function satisfactorily.

Fatigue cracking is a function of babbitt overlay. In the Durex-100 babbitt overlay is held to a 0.003 in. maximum with a production tolerance of from 0.0005 to 0.002 in. to assure that the overlay does not exceed the maximum. Thus, the use of the thin overlay of high-lead babbitt in conjunction with the interlocking bond of the matrix, imparts to this material its high resistance to failure from fatigue.

With high speeds and loads, often crankshafts and crankcases have considerable deflection that results in misalignment of the crank journals in the bearings. Ability of the bearing to conform to these deflections is necessary since the bearing surface becomes tapered, or bell-mouthed, from these deflections. With conventional type babbitt lined bearings, if the taper exceeds the babbitt lining thickness, scoring will occur. The matrix in Durex-100 allows the use of the thin babbitt overlay and when deflections result in taper, the matrix is often exposed, without scoring.

The use of the thin babbitt overlay enables this bearing to carry a 15 to 20 percent heavier load per sq. in. than conventional high-tin or high-lead babbitt bearings. The matrix not only furnishes a better bond, but also functions as a reinforcing structure in the babbitt lining.

Embedability is the ability to allow dirt and foreign particles to embed themselves in the bearing surface, thus preventing the particles from riding the crank journals and wearing or scoring. If the particle is larger than the babbitt overlay thickness, it will embed directly in the matrix.

Durex-100 material is corrosion-resistant to all normal acid conditions resulting from oil oxidation and the acids formed by products of combustion. It is resistant to corrosion with 2 percent oleic acid in the Underwood Corrosion Test Machine. The solidus temperature, temperature at which first liquid phase appears, is 472 deg. F. The standard bearing test is run at 350 deg. F. at the back of the bearing shells.

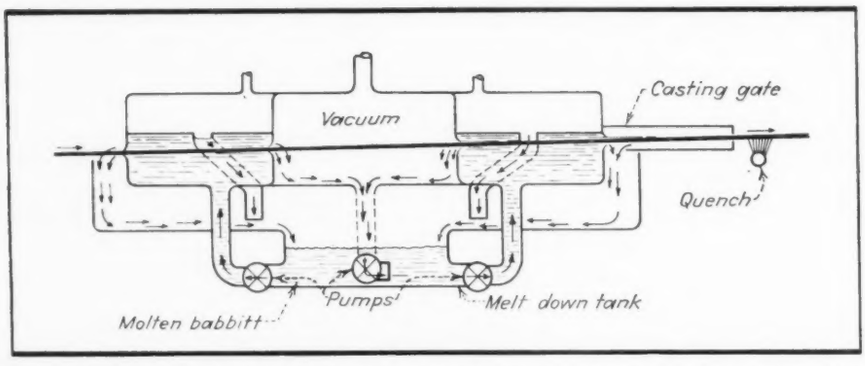


Fig. 1—Schematic sketch showing operation of vacuum impregnating and casting machine for babbitt overlay.

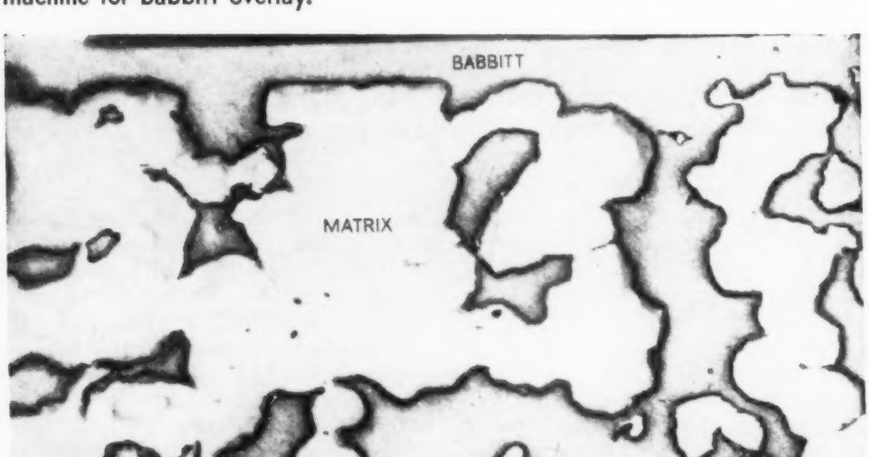


Fig. 2—Relation of steel backing to babbit and matrix of the Durex-100 bearing.

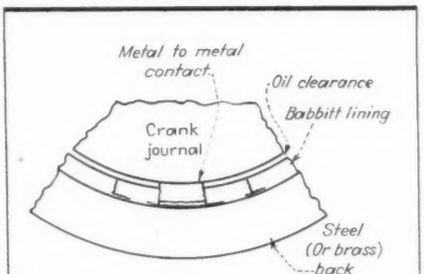


Fig. 3—Fatigue failure in a typical bimetal babbitt bearing.

Bearing Design

All types of engine bearings should be designed into the specific application. There are a number of factors to be considered, among them being the lubrication system; crankcase and crankshaft deflections; deformation of main bearing receiving holes and connecting rod holes; doweling method for bearing caps; crankcase and connecting rod materials; crush loads, stresses in bearing shells and receiving holes; indicated bearing loads from polar diagrams; oil hole, oil groove and tang locations; wall thicknesses; oil clearances; peripheral veloci-

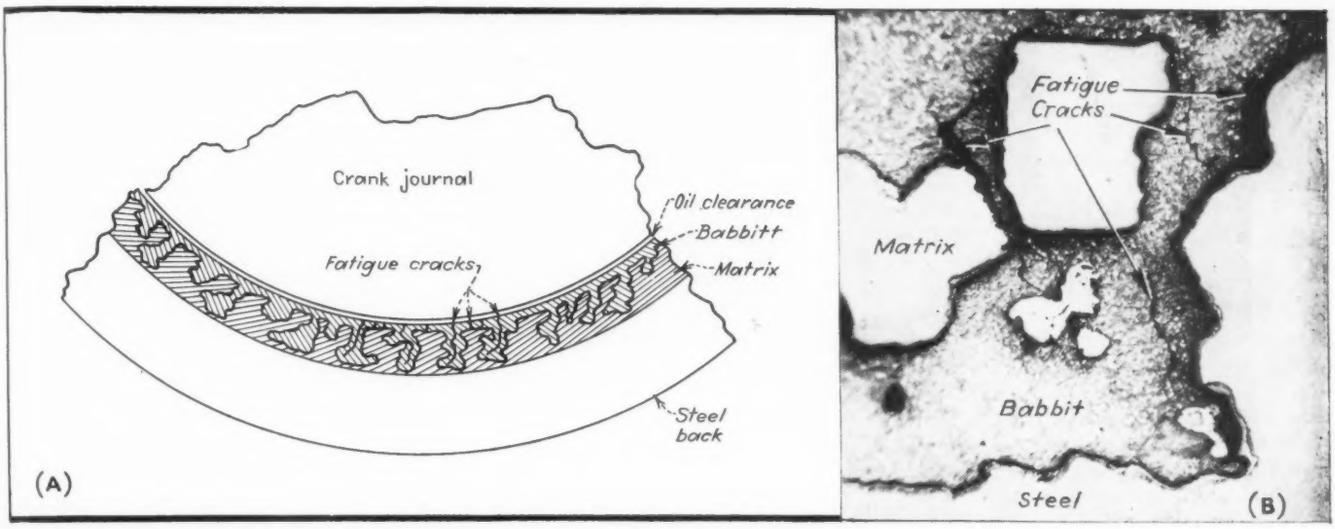


Fig. 4—*(A)* Fatigue failure of babbitt overlay in the Durex-100. Micro-photograph showing interlocking of babbitt by matrix after fatigue cracks occur *(B)*.

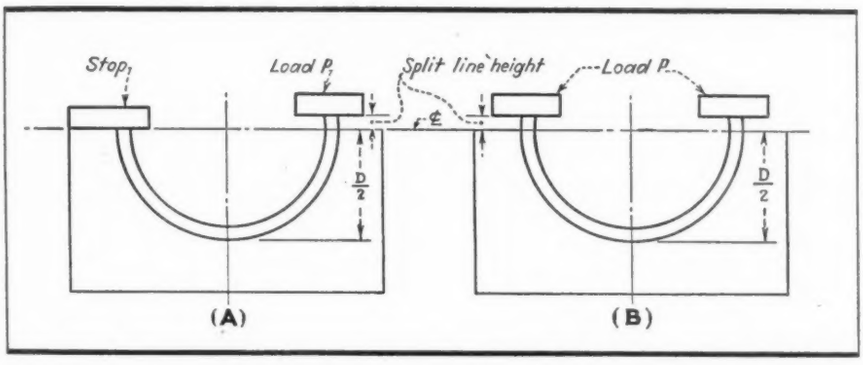


Fig. 5—Method of checking split line heights. *(A)* One end mounted against stop, other end under constant load. *(B)* Equal load on both ends.

ties; thrust loads, for flanged bearings; oil seal design for end bearings; operating temperatures and type of service in the field. In new untested engine designs, there are a number of the above items that are unknown. These unknowns are estimated until sufficient testing can obtain the required information. Lacking the known values on new designs, all that can be done is to fall back on past experiences with similar designs for satisfactory installation of the bearings, pending actual tests.

After establishing such details as oil grooves, oil holes, wall thicknesses, receiving hole sizes, lengths, required tolerances, and tang locations, the crush fit for the bearing is determined. The crush fit for half bearing shells determines the press fit of the two half bearings in the split receiving hole. Lacking known permissible cap loads, the crush is calculated to give a bearing back stress of 30,000 lb. per sq. in., with high limit split line height in a low limit hole.

The stress formula $\delta = \frac{PL}{AE} = \frac{SL}{E}$

is used, where

δ = deformation, in.
P = load per side, lb.
L = peripheral outside diameter length, in.
A = cross sectional area of steel back, sq. in.
E = Young's Modulus. 27×10^6 for Durex-100, experimentally determined, lb. per sq. in.

$S = \frac{P}{A}$ = stress in lb. per sq. in., bearing steel back

Split line heights are checked in two ways; with bearing mounted in a nest having a gage diameter equal to the high limit hole size, Fig. 5(A), with one end against a stop and the other end under a constant load, and, Fig. 5(B), with equal loads on each end. Split line height refers to the amount the bearing half extends above or below a fixed reference line. This reference line ordinarily is the high limit hole half-diameter.

To assure a perfect fit in the gage nest, the gage load is calculated to give a bearing-back stress of 12,000 lb. per sq. in. Under this load, the gage deformation is obtained by substitution in the formula. The total deformation obtained in the receiving hole with high limit stack, high limit split line height in low limit hole, is likewise obtained by substitution in the formula. The high limit crush is obtained by subtracting from the total deformation the sum of the gage deformation and the product of the receiving hole tolerance times $\pi/2$, if the gage diameter equals the high limit hole.

Example: Receiving hole: 2.800 to 2.801
Bearing length: 1.500 to 1.520
Wall thickness: 0.093 to 0.09325, 0.074 steel back
Oil grove: 1/8 wide × 0.052 deep
Gage diameter: 2.801

$A = (0.074 \times 1.510) - 0.125\,[0.74 - (0.093 - 0.052)] = 0.1076$ sq. in.

$P_G = 0.1076 \times 12{,}000 = 1{,}291.2$ lb; use 1,300 lb. for gage load.

With actual half circle periphery L

$L = 4.3998$

However, L used must include total deformation, which is approximately 0.005 for a bearing of this size. Hence,

$L = 4.3998 + 0.005 = 4.4048$.

Gage Deformation:

$$\delta_G = \frac{12{,}082 \times 4.4048}{27 \times 10^6} = 0.0020$$

Total high limit deformation;

$$\delta_H = \frac{30{,}000 \times 4.4048}{27 \times 10^6} = 0.0049$$

High limit crush;

$$0.0049 - \left[0.0020 + \pi\left(\frac{2.801 - 2.800}{2}\right)\right] = 0.0013$$

Standard split line tolerance, except in special applications, for bearings up to 3 1/2 in. outside diameter, is 0.001. Hence, the split line height for this example would be 0.0003 to 0.0013 with 1.300 lb. load on one end, with other end against stop, in a 2.801 diameter gage.

The high limit stack load in pounds on the bearing cap would be:

$P = AS = 0.1076 \times 30{,}000 = 3{,}228$ lb. per side,

$2P = 6{,}456$ lb. total load on the cap.

The low limit stack stress and load would be:

Gage deformation =	0.0020
Low limit split line = +	0.0003
Total deformation δ_L =	0.0023

$$S_L = \frac{0.0023 \times 27 \times 10^6}{(4.3998 + 0.0023)} = 14{,}107 \text{ lb. per sq. in.}$$

Cap load = 2 (0.1076 × 14,107) = 3,036 lb.

When the first experimental engines are available, the crush fit should be checked for hole deformation and bearing back contact.

When the receiving hole is aluminum alloy, a high limit stack stress of 45,000 lb. per sq. in. is used instead of 30,000 lb. per sq. in. This assures positive crush at higher temperatures. It is imperative to check deformation of the hole with this higher crush.

In applications where satisfactory cap loads are known from previous experience, the correct crush for Durex-100 can be obtained directly. For example, an engine is using a thin-babbitt bearing, the proper crush of which has been determined.

The dimensions are:

Receiving hole:	2.600 to 2.6005
Bearing length:	1.310 to 1.330
Wall thickness:	0.062 to 0.06225, 0.057 steel back
Gage diameter:	2.6005
L_G = 4.0849	
Gage split line:	0.0005 to 0.0015 at 600 lb. on one side.

A = 0.0752 sq. in.

S_G = 7,978 lb. per sq. in.

Approximate deformation = 0.004; then L = 4.0849 + 0.004 = 4.0889

$$\delta_G = \frac{7{,}978 \times 4.0889}{27 \times 10^6} = 0.0012$$

For high limit stack:

Low limit hole = 2.6000

(L = 4.0841)

Gage L =	4.0849
Gage δ =	0.0012
$\frac{\pi(2.6005 - 2.6000)}{2}$ =	0.0008
High limit crush =	+0.0015
Total bearing length =	4.0884
Low limit hole =	−4.0841
Total δ_H =	.0043

$$S_H = \frac{0.0043 \times 27 \times 10^6}{4.0884} = 28{,}397 \text{ lb. per sq. in.}$$

P_H = 2,135 lb. per side, or 4,270 lb. on the cap.

It is desired to replace this bearing with Durex-100. The steel back would be 0.046 thick instead of 0.057.

therefore A = 0.06072; P_G = 725 lb.

S_G = 11,940 lb. per sq. in.

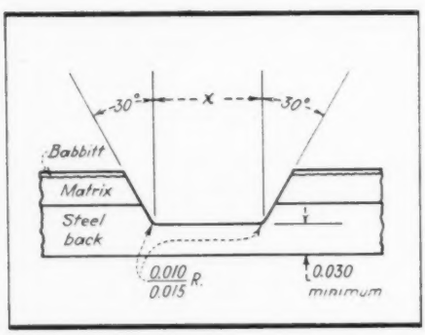


Fig. 6—Design of oil groove developed for Durex-100 bearings.

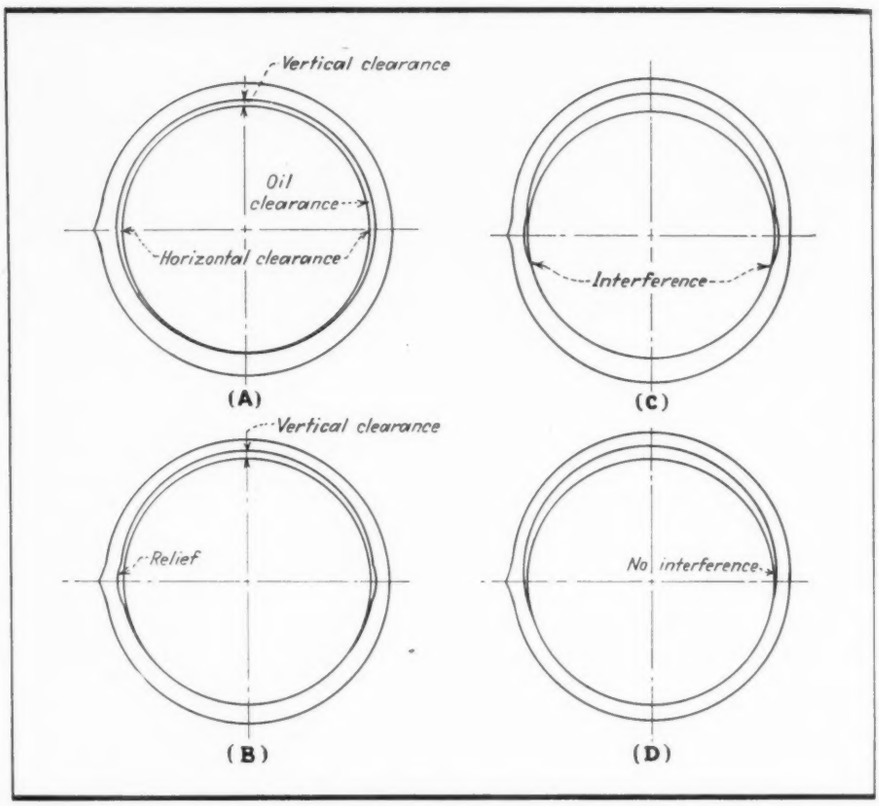


Fig. 7—Bearing designs. *(A)* Eccentric wall type. *(B)* Concentric wall type. *(C)* Interference can result from high crush loads on the concentric wall type. *(D)* High crush loads have less effect on oil wedge in eccentric wall type.

Hence δ_G = 0.0018

2,135 lb. load gives a S_H = 35,161 lb. per sq. in. (A = 0.06072)

δ_H = 0.0053 (total δ with Durex-100)

Gage δ_G =	0.0018
$\frac{0.0005\pi}{2}$ =	+0.0008
	0.0026

0.0053 − 0.0026 = 0.0027, high limit crush, and low limit = 0.0017

The split line height for Durex-100 is, therefore, 0.0017 to 0.0027 with 725 lb. on one end, in a 2.6005 diameter nest.

Tang locations are important and when possible the following conditions should be fulfilled:

1. Not interfere with bolt or dowel holes.
2. Be located at least tang width distance from end of the bearing.
3. Not coincide or overlap oil grooves.
4. When design dictates, it is permissible to locate the tang at one end.

Tangs in upper and lower halves should be on the same side of the receiving hole. This prevents rotation in either direction, and, more important, it obviates the necessity of the receiving hole parting line being on exact center. This latter reason is also why tangs on both sides of upper and lower halves should not be used. With the double tangs, if the parting line of the hole is off center, the crush loads are different between the two halves, and the bearing wall can be distorted by the abnormal crush load acting through the higher loaded tangs.

Oil grooves should be designed such that the wall thickness below the groove has a minimum thickness of 0.030 in. A thinner wall can result in distorted backs, either from machining or from handling. It is preferable to eliminate all sharp corners on the bearing surfaces, because of burrs created in the finish bore-broaching operation. An oil groove design Fig. 6, has been developed that has proved satisfactory for use with this material.

In the majority of applications, it is desirable to use the eccentric wall type of bearing, shown in Fig. 7(A). This design has a varying wall thickness, with the least clearance in the loaded areas. The difference in wall thickness varies from 0.00025 to 0.00100 in., depending on engine characteristics. It is almost impossible to have proper crush without having some slight deformation of the receiving hole. If the bearing wall is designed concentric, it is general practice to broach a 0.0005 to 0.0010 by 3/8 in. relief at the split lines, shown in Fig. 7(B). Often a high crush fit will cause the bearing wall to thicken at the split line, and with the concentric design, this relief prevents split line pinch. Under high crush deformation of the hole, it is entirely possible for the horizontal diameter to close in to where the intersection of the relief and bearing surface rides the crank journal, offering interference, Fig. 7(C), to the continuity of the oil film. With the same

amount of deformation, the eccentric type Fig. 7(D), allows for a uniform oil wedge build-up, that is highly important for correct load distribution.

As with all high-lead babbitt bearings, diametral oil clearances should be on the low side. For engine connecting rod bearings of 2 to 3 in. outside diameter, oil clearances, with eccentric wall thicknesses, should be 0.0007 to 0.0010 in. for low limit, and should not exceed 0.0035 in. for high limit. Main bearing clearances for 2 to 3 1/2 in. outside diameter should be 0.0007 to 0.0015 in. for low, with the high not exceeding 0.0045 in. Larger diameter bearing clearances should be determined by a study of the application in question.

Wall thicknesses are comparable with conventional babbitt lined bearings. It is recommended that, in general, connecting rod bearings have wall thickness ranging from 1/16 to 3/32 in., depending on diameters, and main bearings from 0.072 to 1/8 in. for main bearings up to 3 1/2 in. outside diameter a 3/32 in. wall is satisfactory, if sufficient oil groove depth can be obtained for the application in question.

When laying out new engine designs, it is well to design bearing sizes into the job that are ample in load carrying capacity. Polar load diagrams must be calculated but it should be kept in mind that unknown deflections can increase local unit pressures considerably. If there are no deflections, the entire bearing area is available immediately for supporting the load. However, if deflections are present, the bearing surfaces must conform to these deflections, still retaining sufficient load areas to keep the unit loading within the rated capacity of the bearing material in question.

Bearing loadings are calculated on a projected bearing area basis. The bearing surface is loaded hydraulically by the oil film. As the maximum oil pressures occur on the middle surfaces, the actual local bearing loads change at different points from oil grooves, bearing ends and oil holes. The rated load capacity for a given bearing material is, then, an average value for the entire projected bearing area, and is determined for the most part by test under actual operating conditions. The rated load for Durex-100, under normal operating conditions, is 2,000 lb. per sq. in. of projected bearing area.

It should be pointed out that there are a number of factors that can change this value for given applications and is true for any bearing material under consideration. If one particular application operates satisfactorily with an indicated bearing load of 1,900 lb. per sq. in., it is no criterion that that material would operate in another application with only 1,800 lb. per sq. in. calculated load. It also follows that values of the "rubbing factor" PV and the "bearing factor" $\frac{ZN}{P}$ can only be used for applications having identical characteristics.

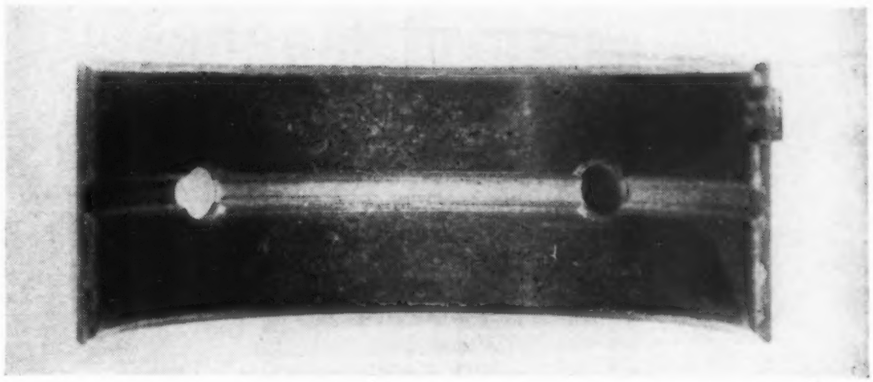


Fig. 8—Typical appearance of Durex-100 bearing after service. Cracks do not indicate early failure.

PV is the product of load per sq. in. of projected bearing area P and V the peripheral velocity of the shaft in ft. per sec. In the factor $\frac{ZN}{P}$, Z is the absolute viscosity of the oil in centipoises, N the shaft r.p.m. and P the load per sq. in. of projected bearing area.

Durex-100 bearings have operated satisfactorily with a PV of 125,000, and yet in some applications, are not satisfactory with a PV as low as 50,000. The bearing factor $\frac{ZN}{P}$ is used as an indicator of performance, but again is useless for applications of different design. Durex-100 operates successfully in an application with a $\frac{ZN}{P}$ value of 1.9, and is not satisfactory in another application having a value of 8.6. In the final analysis, actual testing of the application is the only answer to all of the questions.

Considerable thought should be given to the selection of bearing diameters and lengths. It is recommended that wherever at all possible, the $\frac{L}{D}$ ratio be kept above 1/2, and should never be less than 1/3. It often is possible to improve a design by shortening the length of a bearing, using the additional space to increase the rigidity of the crankshaft. Thus, the localized loading from deflections can be more harmful than increasing the unit loading.

The design of flanged bearings follows the same pattern as straight bearings. The flange thickness cannot be more than the bearing wall thickness, but may be less. It is recommended that the flange thickness be 0.001 to 0.003 in. thinner, as this gives the best flange overlay condition. Flanges considerably thinner can be made by machining inside the flange, at increased cost.

Flanges not requiring machining should have a 0.025 in. maximum radius between the flange back and the bearing back. If the flange is to be machined, a slight undercut at this point is preferable to a tangential radius. Oil grooves, or oil pockets, on the flange surface may or may not be required, depending on the thrust loads encountered.

Cost of bearings can be considerably reduced by making upper and lower halves interchangeable, and by maintaining the same diameter and wall thickness for all main bearings, wherever conditions permit. Length of bearings and location of grooves, oil holes and tangs do not affect cost to any great extent. Often, particularly with new designs, the bearing manufacturer is able to suggest minor detail changes, in line with his individual equipment and processing practices, that can effect considerable savings in cost to the customer.

In service, Durex-100 bearings develop a characteristic appearance that is entirely new in the bearing field. This characteristic appearance is normal, and can show up after comparatively short service. The bearing surfaces develop minute cracks, Fig. 8, which assumes the pattern of the matrix surface. Ordinarily, in conventional bearings, cracks of this nature herald an early failure. This is not true with this bearing and it should not be replaced because of these characteristic cracks.

The true criterion for replacing Durex-100 bearings is actual reduction of wall thickness to where loss of oil pressure results; excessive scratches and gouges from large particles of dirt; loss of babbitt as a result of oil pressure failure, overheating or other abnormal conditions; and other reasons, such as damage in removal or handling. Neither should they be replaced when the matrix shows at the surface. Engines have normal crankshaft deflections which can result in measurable taper, or bell-mouthing. The overlay over the matrix being thin, the babbitt can conform to the tapering and expose the matrix. The bearings will continue to operate with exposed matrix as long as the oil clearance does not increase to where loss of oil pressure results.

In reassembling bearings that have been removed for inspection, care should be taken that all dirt is removed from the bearings and receiving holes. Under no circumstances should an abrasive be used to clean the bearings, as lead-base babbitts are comparatively soft, and will mar and charge easily.

Design of Magnesium Castings For High Properties and Soundness

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Proportions, properties and basic factors that must be considered to assure desired strength and stiffness and sound castings.

WHERE LIGHTWEIGHT is of importance, magnesium castings frequently will be found to be the answer. Their advantages are lightweight, approximately 2/3 that of aluminum, comparatively high strength, and ease of machining. Their disadvantages are their softness, which usually necessitates the use of steel or bronze inserts at points of high loading, their tendency to porosity frequently necessitating impregnation when the casting must be liquid tight, and their sensitivity to high temperatures.

In general, any part that can be cast in aluminum can be cast in magnesium, although the design must be modified to compensate for differences in the properties of the two metals. The low modulus of elasticity of magnesium, its softness, low fatigue strength, temperature sensitivity and different cooling characteristics must be taken into consideration.

Usually the principal reason for using magnesium is to achieve lightness, which may lead a designer to extremes in attempting to minimize dimensions. This should be avoided. Magnesium parts may have somewhat thicker sections, large fillets, and perhaps even added stiffening ribs, and yet be appreciably lighter than if made of any other metal. Even if a wall section of magnesium were as much as 50 percent thicker than an aluminum wall, the magnesium wall would weigh no more. This indicates how much metal can be added to a magnesium part without making it heavier than it would be if cast of aluminum. Where the minimum permissible wall thickness from a casting standpoint has ample strength, the weight of a magnesium casting will be approximately 2/3 that of an aluminum one.

One of the outstanding characteristics of magnesium is its low elastic modulus, which is 6,500,000 lb. per sq. in. as compared to 10,500,000 lb. per sq. in. for aluminum. This low elastic modulus, combined with an exceptionally high tensile strength, creates unusual design problems. Under straight tension a magnesium test specimen will be elongated almost twice as much at the same unit tensile stress as will aluminum, and more than four times as much as steel. The magnesium part must be designed so that it will be stressed a little more than half as much as it would be if made of aluminum, if the elongations are to be the same.

Parts or members that are subjected to bending stresses must be designed with moments of inertia of the cross-section almost twice that required if the part were made of aluminum, assuming equal allowable deflections. Hence for the same depth of section the maximum bending stresses in a magnesium part will be only one-half of those developed in the aluminum part.

Because of the low elastic modulus and high tensile strength, magnesium parts must be designed with far more attention to strains and deflections than parts made of other materials. Familiarity with steel and aluminum creates a tendency to neglect strains and deflections when designing a part to be made of magnesium. Parts not properly designed for stiffness may deflect excessively, possibly transferring loads to associated members and causing a failure.

Fig. 1—Large fillets increase the stiffness of the bolting flange of this cover plate, prevent stress concentration, and facilitate the casting process.

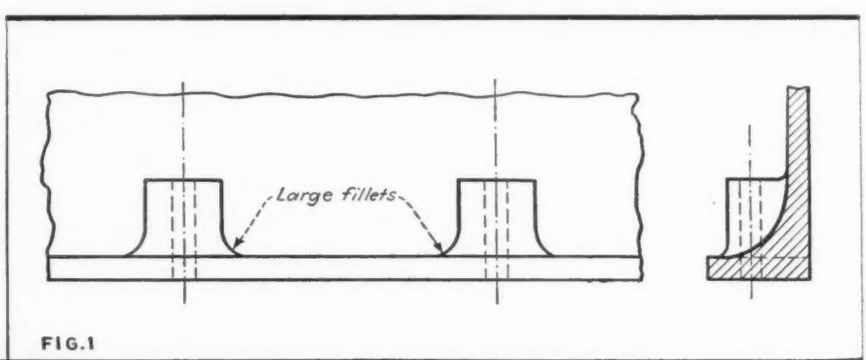

FIG. 1

Fig. 2—A narrow high rib has high stresses concentrated over a small area. Using the correct design of rib, a larger resisting moment is obtained by lower stresses over a much larger area.

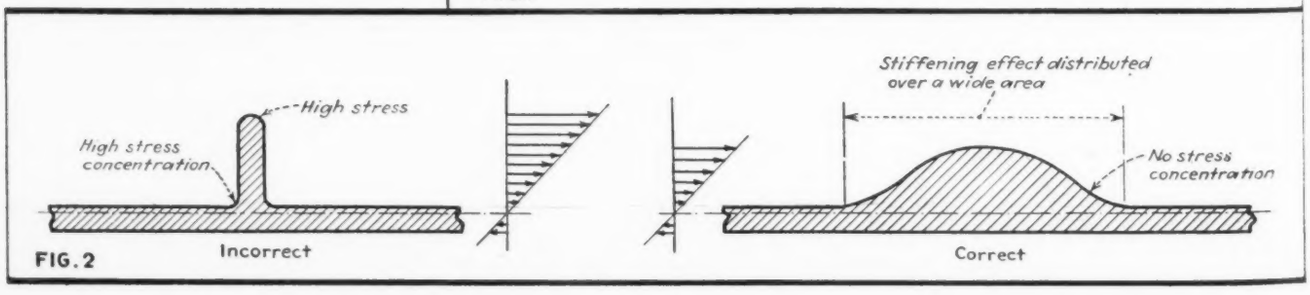

FIG. 2

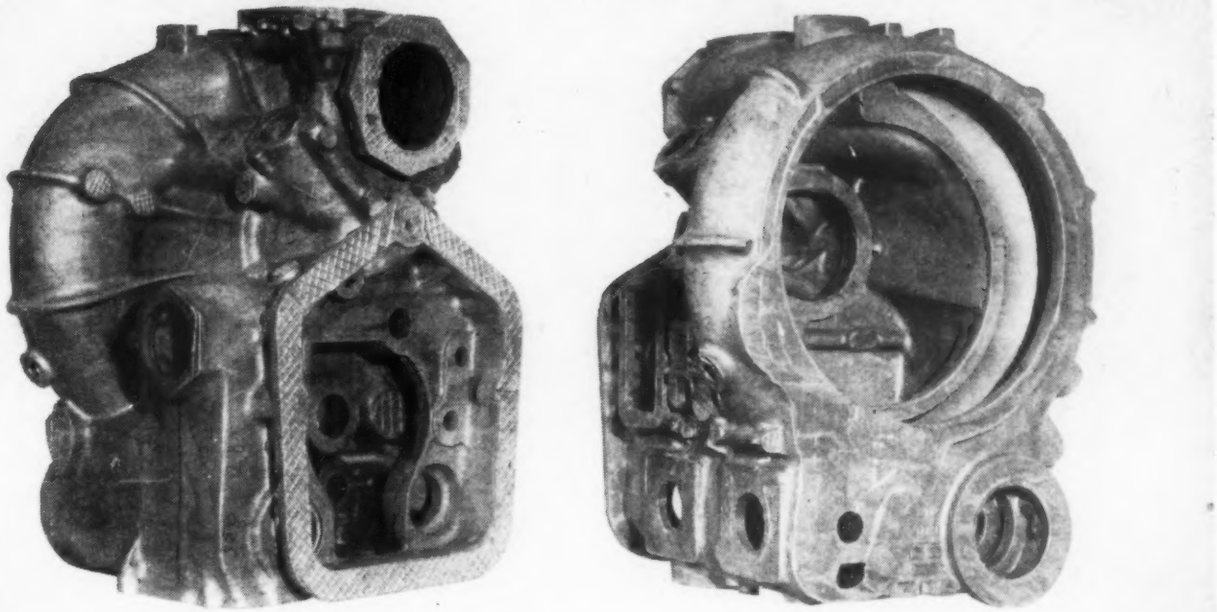

FIG. 3

Fig. 3—In large, intricate magnesium castings such as this accessory housing, the proportioning and positioning of the ribs and bosses is of extreme importance both with reference to stress distribution and foundry requirements. The ribs are low and fillet radii are large.

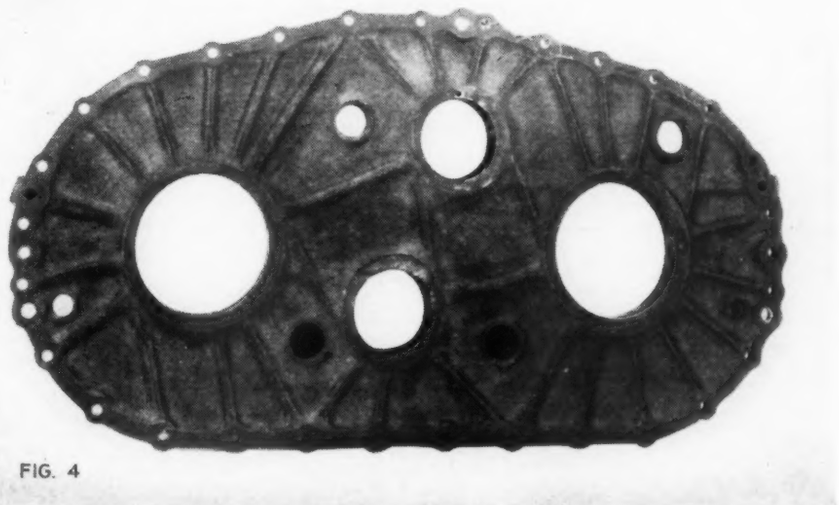

FIG. 4

Fig. 4—A striking example of a properly stiffened gear case cover plate. The ribs are low and wide with large fillet radii to blend them into the web sections, resulting in high stiffness, good stress distribution and absence of stress concentration. Note the beaded edges of the smal lholes.

In addition to the low elastic modulus, special consideration must be given to the low shock resistance of magnesium as compared with aluminum. These two factors require that castings be designed with large fillet radii, about twice those that would be used for iron castings, and with generous tapers from heavier to lighter sections. Fortunately, the necessary provisions to compensate for low elastic modulus and low shock resistance are similar.

The importance of large fillets is illustrated in the design of the bolting flange of a cover plate, shown in Fig. 1. The cover wall sweeps into the flange with a large fillet radius that extends to the edge of the flange, as shown in the sectioned view. This construction increases the stiffness of the bolting flange, prevents stress concentration and, incidentally, facilitates the casting process. In the front view are shown generous fillets between the bosses and flange. Here again the large fillet radius prevents stress concentration and facilitates castings. In addition, the large fillets distribute the bolting pressure over a greater length of flange and increase its stiffness.

Similar to the design of flanges on cover plates is the design of stiffening ribs, which are required more frequently in magnesium parts than in aluminum parts because of the lower elastic modulus of magnesium. The low elastic modulus of magnesium in combination with its high tensile strength accentuates the requirements for proper proportioning of stiffening ribs. Many steel parts and aluminum parts have been designed with stiffening ribs similar to the incorrect design shown in Fig. 2. In spite of the fact that such parts have rendered good service, primarily because of an extremely high "factor of safety," the design of the parts could have been greatly improved by modifications in the proportions of the ribs.

This was strikingly demonstrated in analyses and tests made on various designs of aluminum engine crankcases. It was found that extremely high ribs prevented the metal in the web from taking any appreciable load and concentrated the stresses in the top of the ribs. Reducing the height of the rib and increasing fillet radii, distributed the stresses over a greater area, and increased the load carrying capacity of the structure. The ribs around the scroll of the accessories housing of Fig. 3 and those on the gear case cover of Fig. 4 are examples of the low wide

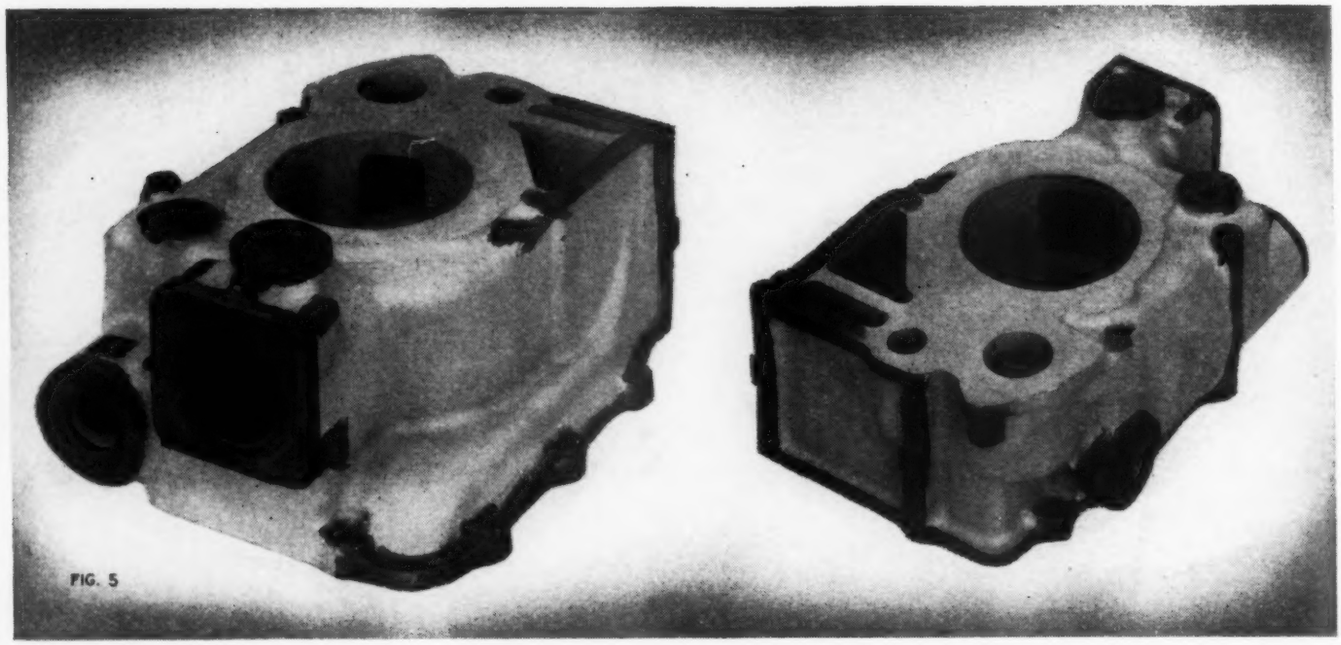

FIG. 5

Fig. 5—This oil pump adapter is an example of a small casting involving complicated cored oil passages.

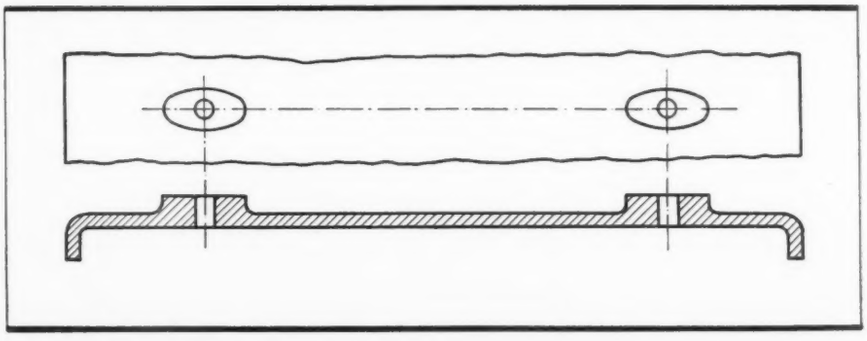

Fig 6—Bosses that are an appreciable distance apart should be elongated in the direction of their center line in order to compensate for variable shrinkage, or the diameter of the basses should be increased correspondingly.

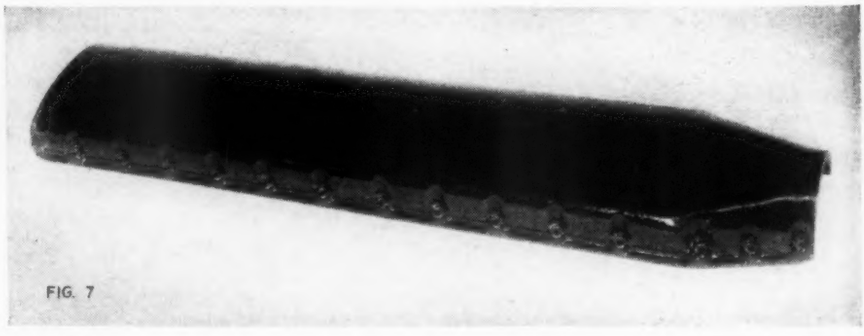

FIG. 7

Fig. 7—A comparatively simple design of casting but presenting foundry problems because of its size, about 40 in. long, and thin walls. It was cast to the minimum thickness practical for the foundry and then machined to the desired thinness.

ribs used to prevent stress concentrations in the rib outeredges.

When the loads on a magnesium casting are principally bending moments, and deflections must be limited, the moments of inertia of cross-sections must be increased to compensate for the lower elastic modulus of magnesium. Usually there is sufficient room to permit the necessary dimensional increases. For geometrically similar sections, an increase of less than 20 percent in linear cross-sectional dimensions doubles the moments of inertia. Therefore, it is rarely difficult to obtain the desired increase in stiffness. However, with straight tension or compression loads the cross-sectional area must be almost doubled if the strains are to be no greater than those in the part when made of aluminum.

The softness and low elastic modulus of magnesium make its use impractical for some applications. For example, in an engine crankcase of aluminum wherein it would not be feasible to double the bearing supporting areas, if magnesium were used the compression of the metal supporting the bearings would be almost twice as great. These strains would cause corresponding deflections of the crankshaft. On the other hand, if the cross-sectional area of the bearing housing were increased enough to compensate for the lower elastic modulus of the magnesium, other dimensions throughout the engine would have to be increased correspondingly. Much of the weight advantage of magnesium would be lost and often there would not be room for the additional volume of metal required.

Another difficulty in using magnesium for engine crankcase arises from the greater softness of the metal at crankcase operating temperatures. At this temperature, approximately 250 deg. F., the metal is too soft to properly support heavily loaded bearings, and the metal may flow plastically under the operating loads.

The greater plasticity of magnesium at even moderately elevated temperatures is also a factor in the behavior of magnesium when it is being cast. Unlike magnesium, aluminum is capable of developing appreciable stresses when at 400 to 500 deg. F. Thus, aluminum, solidifying at about 1,100 deg. F. and cooling to 400 or 500 deg., will

exert considerable pressure against those mold surfaces that resist further shrinkage. Pressures or shrinkage forces may be sufficient to crush a core or at least compel the core sand to yield to the continued contraction of the enveloping aluminum.

However, when magnesium solidifies and cools to 500 deg. F. it is still extremely plastic and retains that plasticity to a considerable degree down to a temperature of 200 to 300 deg. F. As a result the metal exerts little pressure upon cores and is prevented from contracting, so that it conforms to the mold dimensions by plastic flow. This effect is not quite as noticeable when green molding sand is used instead of baked sand cores on account of the greater strength and hardness of the latter.

Because of the high plasticity of magnesium through a large part of its cooling range, magnesium castings do not shrink uniformly. Diameters of cored holes in castings are often practically the same as the distance between the core prints on the pattern. The metal between the two cored holes is stretched and thus is reduced in thickness.

Because of the many factors involved, there is usually considerable variation in the distance between bosses that are an appreciable distance apart. Hence it is advisable to increase the diameter of bosses or elongate them in the direction of the variable shrinkage in order to compensate for variations in distance between bosses. This will assure sufficient metal when the center distances between holes through bosses must be held to close tolerances. In determining diameters of bosses, allowances must also be made for placing under the heads of capscrews or bolts hardened steel washers, which should not overhang the edge of the bosses.

Casting difficulties can be reduced by properly proportioning the part since the shapes that are the best for strength and deflection are also usually best for the production of sound castings. Thus the avoidance of abrupt changes in cross-sections, the use of large fillet radii and the avoidance of intricacies in the design all contribute in making good castings.

Often the minimum wall thickness of a casting is determined by foundry limitations rather than strength requirements. When thinner walls are essential it is better to cast the wall to the thickness practical for the foundry and then machine it or grind it to the desired thickness. The cylinder head cover, Fig. 7, is an example. It is generally advisable to permit foundry men to increase wall thickness if they deem it desirable and to specify a total weight tolerance. This gives the foundry considerable leeway in modifying the distribution of metal to suit their requirements, but prevents them from increasing the weight. The accessories housing Fig. 3 is so controlled.

As soon as the rough drawing of a proposed magnesium casting has been prepared the pattern shop and foundry should be consulted for their recommendations as to size and location of ribs, bosses, fillets, and other details, both from a pattern parting standpoint as well as from considerations of metal flow. It is then often possible to complete on the drafting board a design that will enable the foundry to make a casting having the best distribution of material.

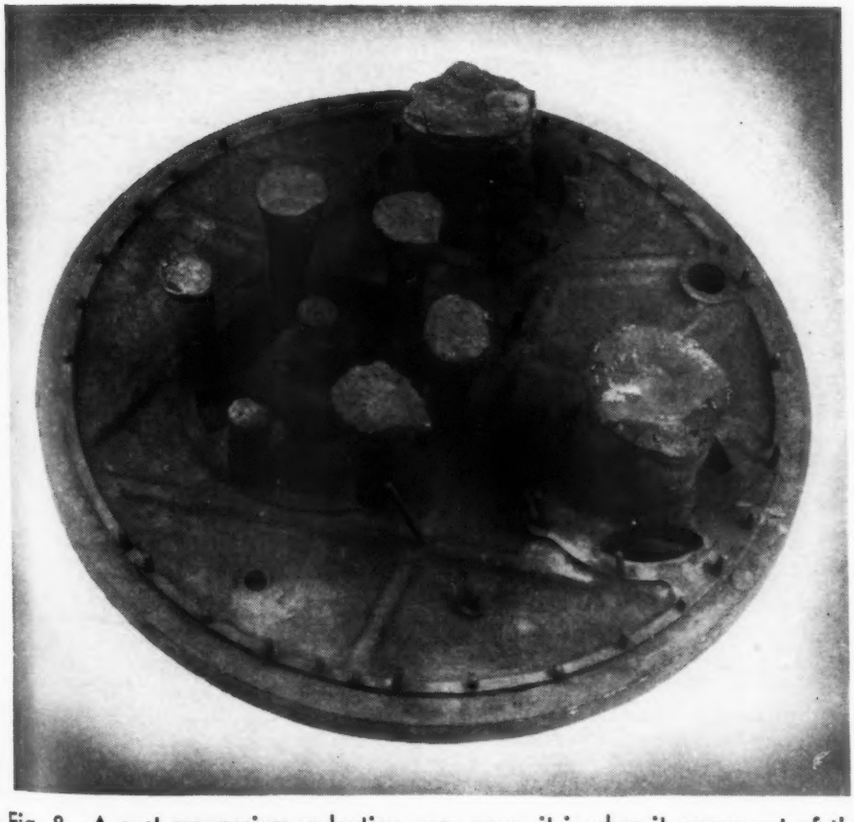

Fig. 8—A cast magnesium reduction gear cover it is when it comes out of the mold with gates and risers still on.

Recommended Alloys

The two magnesium alloys that are most widely used for castings are Dow C or AM 260 and Dow H or AM 265, designated as AZ92 and AZ63 respectively in ASTM Specification B80-44T. The AZ92 alloy requires careful heat-treatment and is a little harder to cast in intricate sections than is AZ63 alloy. Heat-treatment for AZ92 or Dow C alloy, as recommended by Dow Chemical Company, is 20 hr. at 765 to 775 deg. F., quench in air and then age at 350 deg. F. plus or minus 10 deg. F. for 16 hr. For its corresponding alloy AM 260 American Magnesium Corporation recommends a shorter heat-treatment of 16 hr. at 780 deg. F. with the same quench and aging that Dow recommends.

Special care must be exercised in controlling temperature for aging this alloy. At the recommended temperature of 350 deg. F. plus or minus 10 deg., the hardness increases rapidly to maximum and then for a few hours drops relatively slowly. If a higher aging temperature were used the hardness would increase to its maximum at a somewhat more rapid rate but would also decrease at an increasingly rapid rate. This would make it difficult to stop the aging process at exactly the right time to give the desired hardness. A small difference in time would result in a disproportionately greater difference in hardness.

The AZ63 alloy is not as sensitive to changes in the aging temperature although the specified aging treatment is also 350 deg. F. plus or minus 10 deg. for 16 hr. The recommended heat-treatment for this alloy for 12 hr. at 720 to 730 deg. F.

In addition to considerations of differences in stresses and strains, and the possibilities of heat treatment, difficulties that might result from the softness and low abrasion resistance of magnesium must also be overcome in design. Thus, it is not advisable to mount bearing races directly in magnesium bores because the metal will wear rapidly. Steel or bronze sleeves are used to hold the outer races of anti-friction bearings, thus distributing the load over a larger area. These sleeves have a light press fit. For the same reason bronze or steel inserts are used where tapped holes are required for capscrews that are to be removed frequently, thus avoiding the fast wear that would occur on magnesium threads. As previously mentioned, washers must be used under the heads of capscrews and bolts to prevent scoring and wearing of magnesium surfaces during service or in the repeated tightening and loosening of the screws and bolts.

NEW MATERIALS AND PARTS

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Gasketing

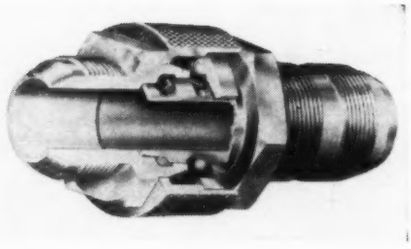
Products Research Co., 634 S. Western Ave., Dept. A110, Los Angeles 5, Calif.

Chrome Lock Gasketing has an adhesive back. It is unnecessary to tie, lace or tape the gasket onto vertical or inverted flanges. These gaskets have a crinolin liner upon which the template may be laid and either scribed or marked with an ordinary lead pencil. Quantities of gaskets may be cut at one time and with the liner left in place, stacked in parts bins without sticking together or collecting dirt and filings. The liner stabilizes the gasketing during cutting. Chrome Lock Gasketing is supplied in four types, #8 and #16 without the adhesive back and #8A and #16A with adhesive back. The gasketing is packed in both rolls and slit rolls. Among the advantages claimed for this product are: flame resistance, fuel resistance, rust-inhibition, anti-wicking, lamination, non-oxidation, non-hydroscopic, compressibility, longer life, cushioning, and ease of handling.

Quick Coupling

Roylyn Mechanical Laboratory, 8928 Santa Monica Boulevard, Los Angeles 45, Calif.

Based on the "inclined plane and wheel principle," the Roylyn coupling employs three major parts: the cam ring, ball cage, and nipple. By rotating the cam collar, steel

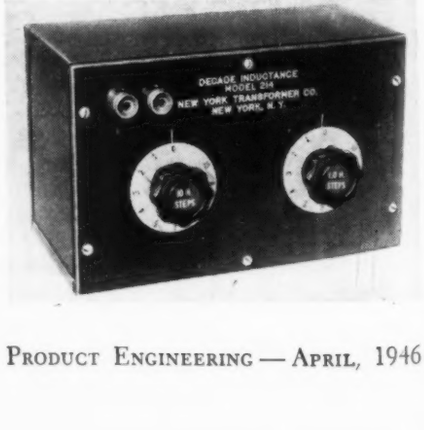


balls are forced inward into a groove in the nipple forcing the halves together. The gasket retained in the ball cage provides a seal against dirt as well as being the separating spring force necessary to the operation of the lock. A slight shoulder on the cam assures a lock; application of more pressure tightens it, and the cam collar unlocks it. Tests made on an alloy steel model showed a temperature operating range from minus 65 deg. F. to plus 300 deg. F. with safe pressure limits of 1,680 lb. per sq. in. for the 2 in. coupling and 11,500 lb. per sq. in. for the ¼ in. unit. Couplings are available in aluminum, brass, alloy or stainless steel with correct gaskets to withstand the fuels, oils, and acids used in various industries. Pipe threads or flared tube connections are optional with caps to fit all sizes of nipples. Standard thread sizes run from ¼ in. to 2 in. larger sizes available on special order.

Inductance Decades

New York Transformer Company, 62 William St., New York 5, N. Y.

The inductance ranges are from 0.001 henry steps to 100 henries total. These units are shielded against external fields and are available in enclosed cases with two decades per case. On special order, these can be made with three or five decades in a single case. These decades are adjusted to within 2 percent at 1,000 cycles, except for the 100 henry decade which is adjusted at 200 cycles. The inductances will not change with

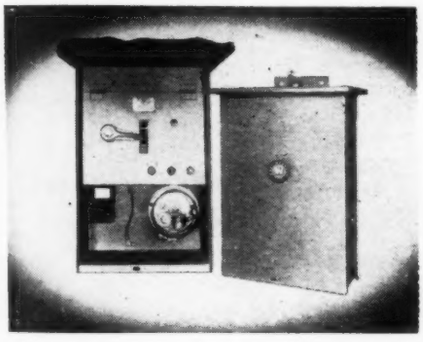


a variation of a.c. currents or voltages. The frequency range of these units is 30 to 20,000 cycles. The 0.01 and 0.1 heavy decades have a Q of 40 to 45 at 4,000 cycles, dropping to 15 at 400 cycles and 15,000 cycles. The 1 and 10 henry decades have a Q of 35 to 40 at 1,000 cycles, dropping to 15 at 200 and 10,000 cycles. The 100 henry decade has its maximum Q around 200 cycles. These decades are not designed to work with d.c. currents.

Oil Field Pumping Control

Westinghouse Electric Corp., Box 868, Pittsburgh, Pa.

Designed for automatic starting and stopping of oil field pumping motors. Weatherproof enclosure permits outdoor, pole mounting close to the load. The dead front inner door protects the operator from live parts, when cabinet door is opened. Starters are available in two basic types, each providing overload and low voltage protec-

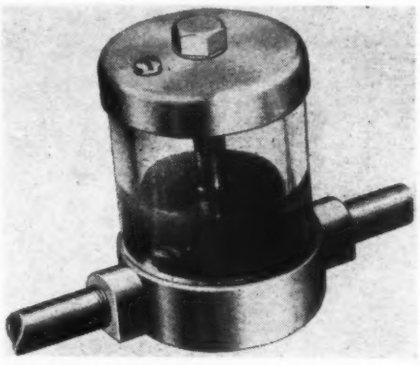


tion. The automatic unit includes AB breaker, "De-ion" linestarters, lightning arrester, hand reset low voltage relay, "Hand-Off-Automatic" selector switch to permit manual operation, socket and time switch. The time switch automatically controls specific pumping periods during the day. The local control unit includes AB breaker, "De-ion" linestarter, lightning arrester, and start-stop pushbutton. Ratings are from 1 to 25 h.p., 110, 220, 440-600 volts.

Air Tool Lubricator

CCA Products Engineering, P. O. Box 671, Glendale, Calif.

The CCA Lube has a full view, nonbreakable transparent plastic window with "O" rings for top and bottom seals. Quantity of oil in the lubricator is visible at all times. Lubricant is regulated by a needle valve located on the air outlet side. This "Lube-Mist" regulator is adjustable to meet varying equipment requirements. The filler cap and adjusting aperture is located directly above the regular valve. Since the Lube works only when air operated equipment is in use, the device is automatic, permitting the correct amount of oil to mix with working air. Adjustability of the Lube prevents oil flooding and oil starvation, eliminates freezing of pneumatic equipment and

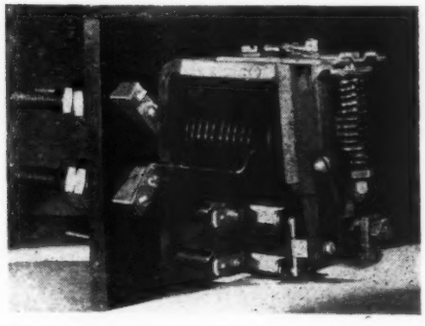


cuts down maintenance repairs. The needle valve can be turned off altogether in cases where no lubrication is required. Available in $\frac{1}{4}$ in. and $\frac{3}{8}$ in. standard pipe line sizes.

Magnetic Overload and Jamming Relay

Westinghouse Electric Corp., P. O. Box 868, Pittsburgh 30, Pa.

The single-break normally closed main contacts and the double-break auxiliary contacts are suitable for carrying 5 amperes continuously and for interrupting a d.c. inductive coil load of 150-volt-amperes maximum.



Type AYJ relays are operated by a series of copper-strap-wound coil. Coils and coil studs are available for currents from 75 to 625 amperes. The coils and auxiliary contact parts are insulated from the relay frames for 600 volts. Of unit construction with a knife-edge bearing between the armature and the frame, the relays are assembled and tested at the factory before shipment. Ground armature and frame surfaces are plated with hard chromium for protection against corrosion and wear.

Micro Conductivity Cell

Industrial Instruments, Inc., 17 Pollock Ave., Jersey City 5, N. J.

The Pyrex glass dip cell measures $\frac{1}{2}$ in. outside diameter by 6 in. long. The platinized platinum electrodes are so positioned that only a few cubic centimeters of sample are required. A flexible rubber sleeve protects the lead wires. This type of cell is used in checking solutions in small original containers or sample bottles. A selection of cell constants from 0.1 up permits the checking of any solutions ranging from pure distilled water to fuming sulphuric acid, when the cell is used in combination with a suitably calibrated solu-bridge or a conductivity bridge.

Flexible Tubing

Warner Brothers Company, Spiratube Div., Bridgeport, Conn.,

A type of flexible tubing, non-collapsible under plus or minus pressures and retractable to about one-eighth its extended length for portable or semi-permanent ventilation or any handling of air, gases or light solids. The spring steel helix core causes it to spring out to its fully extended length, and it will stay in this position regardless of whether on pressure or suction. The inside surface is free of wire ridges and sharp bends can be made with a slight reduction of air flow and without the use of elbows or special fittings. The standard Spiratube is made of long fiber duck, having a bursting strength of 170 lb. per. sq. in. and the fabric is processed fire-

resistant and covered with tough, durable thermoplastic. It can also be made to specification in a variety of other fabrics for special applications. Spiral-stitching is done with a double seam of rot-proofed thread. There is no exposed metal inside or out. Spiratube is furnished in standard diameters from 3 in. to 16 in. and in lengths of 10, 15 and 25 ft. Built-in couplings permit joining or disconnecting.

Resin Finish

Resinous Products & Chemical Co., Philadelphia, Pa.

Duraplex ND-77B is a non-drying, phthalic alkyd designed for use in conjunction with Uformite, urea formaldehyde resins or nitrocellulose, to produce fast baking finishes at high temperatures. It has excellent pigment stability, good adhesion and protects finishes against inadvertent overbaking. Duraplex ND-77B is soluble in aromatic hydrocarbons, hydrogenated solvents, chlorinated hydrocarbons, esters such as ethyl and butyl acetate, ketones such as acetone and methyl ethyl ketone, glycol ethers and esters such as Cellosolve and Cellosolve acetate. Mineral thinner is tolerated by the new resin in ratios of 3 parts thinner to 1 part resin in xylol solution, with alcohol tolerated in lesser amounts, the maximum ratio being equal

parts of alcohol and resin solution. Films of Duraplex ND-77B in combination with Uformite or nitrocellulose require a variety of baking schedules according to the formulation and the method of application. In some cases a coat of primer is applied and baked for 20 minutes at 340 deg. F., followed by a light sanding, a mist coat and a full coat of enamel, air-dried and baked for 45 minutes at 300 deg. F. Lower baking temperatures require correspondingly longer schedules.

Interval Timer

Industrial Timer Corp., 117 *Edison Place, Newark 5, N. J.*

The P-49 Model Timer is equipped with a receptacle which can be attached to a printer platen switch for setting in operation the P-49 at whatever time interval was previously selected. It allows the operator to use a foot switch control instead of the push button, if the Time-o-Lite is not adjacent to the apparatus. The double scale on the dial has large, clear divisions and

numbers; the outer scale for setting the time interval, and on which the large white pointer is moved to the desired time setting. The inner scale with the red pointer moves counter-clockwise from the set point to zero, and determines the exact amount of time elapsed.

Stack Analysis Instrument

Davis Emergency Equipment Co. Inc., 45 Halleck Street, Newark 4, N. J.

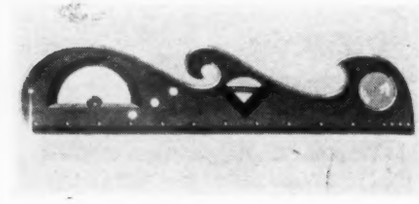
All readings on this instrument are taken on one meter. CO_2 percentage readings are obtained from gas samples collected through a hand aspirator bulb. Stack temperatures are obtained electrically from a thermocouple mounted in the gas sampling tube. Draft measurement is obtained through a separate tube. The meter dial reads 0 to 20 per cent CO_2 in black figures, temperature on a red scale 0 to 1,000 deg. F. and draft in tenths of inches of water on a green scale. A safety switch automatically shuts

off battery current on closing the cover of the instrument box. Portability is obtained by having sampling hose, hand aspirator, thermo couple sampling and draft sampling tubes located in the one case, measuring 12 in. x 13 in. x 5 in. Weight of case with complete instrument is 11 lbs.

Combination Ruler

Parva Products Co., West Haven 16, Conn.

This item comprises eight instruments in one: french curve, magnifying glass, ruler, letter weigher, compass, protractor, level, and mitre. It is of ivory plastic construction with blue graduations.



U.H.F. Beam Tetrode

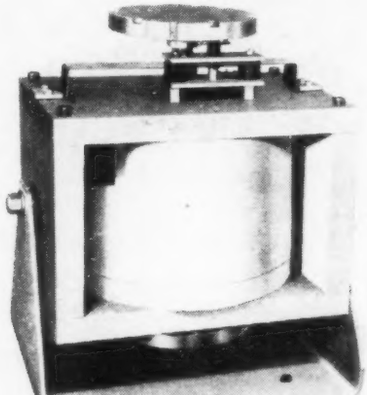
Taylor Tubes, Inc., 2312 Wabansia Ave., Chicago, Ill.

Operating with full power input to 250 mc. and at halfpower input to 400 mc., this tetrode has a power output of over 125 watts (Class C, telegraphy) in these ultra high frequency regions. The tube possesses a four-pin ceramic base and the plate connection is brought out at the top of the envelope. The overall size of the tube is $4\frac{7}{8}$ in. and the maximum diameter is $1\frac{5}{8}$ in. Electrical characteristics: filament, thoriated tungsten, 6.3 volts (a.c. or d.c.) at 3 amps; Mu—65 approx.; Mutual conductance at lb .08—2750 micromhos; Interelectrode capacitances—Input to plate 0.2 mmf, Input 6.5 mmf, Output 1.8 mmf. Typical operation, Class C telegraphy: d.c. plate volts—1500; d.c. Grid No. 1 volts—300; d.c. Grid No. 2 volts—375; d.c. plate current—110 ma; d.c. grid current—15 ma. (approx.); d.c. screen current—22 ma; plate dissipation (max.)—35 watts; peak rf. grid input volts—350 (approx.); driving power—4.5 watts (approx.); plate power output (to 250 mc.)—130 watts. Typical operating conditions, Class C, plate modulated with a maximum modulation factor of 1.0: d.c. plate volts—1,000; d.c. Grid No. 1 volts—200; d.c. Grid No. 2 volts—300 d.c. plate current—85 ma; d.c. grid current—10 ma; peak rf. grid input voltage—250; driving power—2 watts; plate power output—60 watts.

Vibration Exciter

The MB Manufacturing Co., Inc., 333 East St., New Haven 11, Conn.

An electrodynamic unit, designed to deliver a peak force of 200 lbs. over a wide frequency range. A product or part can be excited to its resonant modes of vibration with a pure sine wave force that can be controlled in both frequency and amplitude. This equipment has the power to vibrate mechanical structures and parts to destruction. It locates noise sources, and duplicates age-loosening of parts. When operating the machine above its own mechanical resonance, vibration pickups (acceleration, velocity and displacement types) can be calibrated with a wave form as good as that of the current source. Rated accelerations to

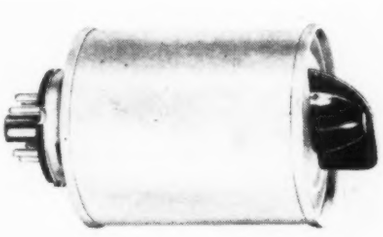


20 g. are produced, with a peak of 40 g. obtainable for short periods. Maximum table travel is 1.0 in. A standard signal generator attached to the shake table will allow a check of the amplitude in comparison to the pick-up being calibrated. The table is adjustable for motion in any direction. Total weight of this Vibration Exciter is 685 lbs. overall dimensions are 23x24x14 in. A motor-generator-alternator power supply is available for use with this equipment.

Self-timing Interrupter

Electronic Controls, Inc., 44 Summer Ave., Newark 4, N. J.

The ECI-Self-Timing Interrupter unit is comprised of a glass-enclosed thermal element of the hot-wire type, a small power thermocouple sampling and draft sampling of current between the thermal element and the relay coil. The device can be supplied with a fixed, predetermined rate of inter-



ruption or with an external variable adjustment. The fixed unit can be supplied in either open frame construction or in plug-in metal enclosures, dust cover or hermetically sealed, while the adjustable unit is available in plug-in dust cover enclosures only. Timing Range: 1-12 pulses per second. Voltages: To 32 volts d.c. and 125 volts, 60 cycle a.c. Contacts: s.p.s.t., d.p.s.t., d.p.d.t. Contact Rating: 10 amps. (Non-inductive load at sea level).

Electrical Contacts

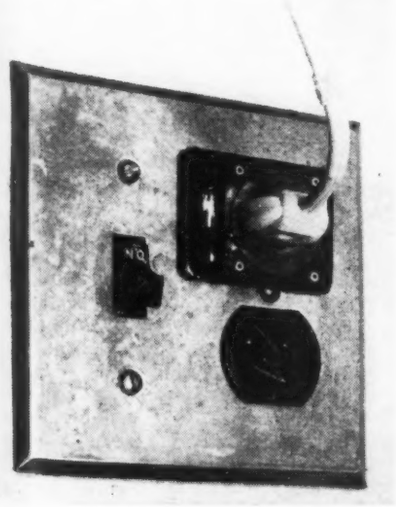
Gibson Electric Co., 8358 Frankstown Ave., Pittsburgh 21, Pa.

Characteristics claimed for these "Gibsiloy" electrical contacts made from silver tungsten and silver tungsten carbide include high current carrying capacity, good non-welding characteristics, and long life. Made from metal powders, these contacts comprise a range of combinations in the silver tungsten series from 10 percent to 80 percent tungsten, and in the silver tungsten carbide series from 20 percent to 80 percent tungsten carbide, with hardnesses from 80 to 100 Rockwell B.

Plug-in Pilot Light

Industrial Devices, Inc., 22 State Road, Edgewater, N. J.

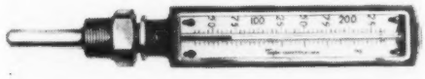
This neon-light indicator takes the usual plug prongs slipping through its slots and into the standard electric outlet or the female plug. The device is for use with any standard 110 volt a.c. or d.c. outlet. It is useful with soldering irons, electric heaters, toasters, percolators and other appliances that may be used on switch-controlled circuits, or with plugs that should be pulled out when the equipment is inoperative. The red glow is also handy in dark places for locating plugged-in cords and outlets.



Industrial Thermometer

Taylor Instrument Companies, Rochester 1, New York

Designed for use where space is limited and instruments are subjected to unusual vibration, this thermometer has a Binoc tube encased in a one-piece housing. There are a variety of stem forms: Straight, 90 deg. angle, 90 deg. right side angle, 90 deg. left



side angle, or 45 deg. reclined (135 deg. oblique) angle, which permit the selection of the proper thermometer for correct installation and greatest ease in reading. Ranges available are: Minus 40 to +110 deg. F., 30 deg. to 180 deg. F., 30 deg. to 240 deg. F., and 200 deg. to 500 deg. F.

Flexible Tubing

The Seamlex Co. Inc., 27-27 Jackson Ave., Long Island City, N. Y.

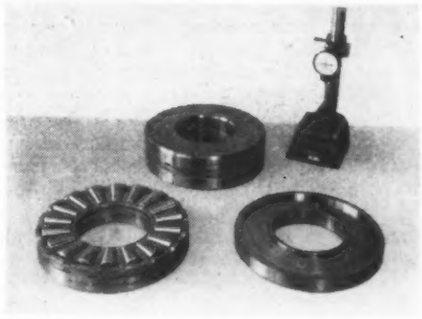
Seamless flexible tubing in stainless steel. In the cut, one end shows the helical convolutions in cross section; the other end illustrates an integral cylindrical extension suitable for attaching flare-type fittings. The

flexible tubing shown is usually provided with metallic braid jacket for internal pressure requirements. Any type of end connection can be furnished. Standard sizes range from $\frac{1}{16}$ in. i.d. to $\frac{1}{4}$ in. i.d. inclusive.

Conical Roller Thrust Bearings

The Kaydon Engineering Corp., Muskegon, Mich.

The design of this bearing is such that the apex of the cone formed by the rollers meets at the true center of the bearing. This permits the rollers to align themselves between the tapered faces and the outside rib of the raceways. The one-piece bronze cage acts



only as a separator. Conical roller thrust bearings are designed to carry thrust loads only. Mountings should be designed to avoid radial load interference. A complete series of standard sizes from $9\frac{7}{8}$ in. O.D. to $19\frac{1}{2}$ in. O.D. and load capacity to 440,000 lbs. are available.

Radial Bearings

Nice Ball Bearing Co., 30th and Hunting Park Ave., Philadelphia 40, Pa.

These close tolerance, "ground all over" units are recommended for medium loads and for maximum speeds of 3,000 to 5,000 r.p.m. Nice "1600" bearings have one-piece inner and outer races. A ball retainer, or

separator, is used in the annulars. All retainers are of the two-piece type and the balls are of close tolerance, highly polished, chrome-alloy steel. These bearings are available double-shielded, with one shield, or without shields, and with the exception of double-shielded units, which are grease-packed as standard, can be furnished with or without grease packing.

Measuring Instrument

The American Instrument Co., Silver Spring, Md.

The Filmeter, NRL Model 1, an electronic instrument for measuring the thickness of paint, varnish, lacquer, ceramics, plastics, and other non-conducting coatings which may be deposited on non-magnetic base metals such as aluminum, brass, copper and bronze. The instrument measures coating thickness from zero to 0.005 in., with an accuracy of 3 percent of full scale. Measurements may be made on any flat surface, or on convex or concave surfaces having a radius of curvature of not less than 6 in.

The Filmeter consists of a battery-operated electronic beat-frequency oscillator in a 7x7x7-in. steel case. The inductance coil of one oscillator is mounted in the end of a tripod-mounted inductor, and is connected to the instrument by a shielded rubber-covered cable. Earphones enable the operator to determine when the two oscillators are set to the same frequency. Entire instrument weighs approximately 11 lb., and may be used as a portable field instrument or on a laboratory bench.

Deflection Pick-Up

Stevens-Arnold Co., 22 Elkins St., South Boston, Mass.

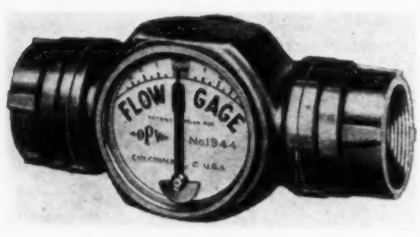
An hermetically sealed electrical unit which translates deflections or pressure variations, applied to its plunger, into linear changes in its d.c. output voltage. Readings are obtained in the range of 0.0005 in. to 0.1 in. movement of the plunger and reliable response up to 100 cycles per second is

claimed. The pick-up may be used under heavy vibration, at temperatures to 300 deg. F. and it may be submerged in water. Power supply may be 115 volts a.c. or an 8, 12, or 24 volt battery. Results may be recorded on a continuous strip chart.

Magnetic Flow Gage

The Ohio Pattern Works and Foundry Co., 2735 Colerain Ave., Cincinnati 25, Ohio.

The OPW No. 1944 gage is non-rotating and operates in either direction and in any position entirely by magnetism. It is equipped with identical indicators on two sides. The flow actuated plunger of this gage carries a magnetic cylinder which causes the indicator hands to move synchronously when flow occurs. The direction and extent of this movement is dependent on the rate



of flow. The plunger and indicator hands are returned to neutral (no flow) position by springs when flow ceases. Any viscosity of liquid can be gaged to 150 lbs. pressure and it is claimed that extremely low flow can be handled as readily as high velocity. Available in $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$ and 2 in. sizes.

Jewel Bearing Assembly

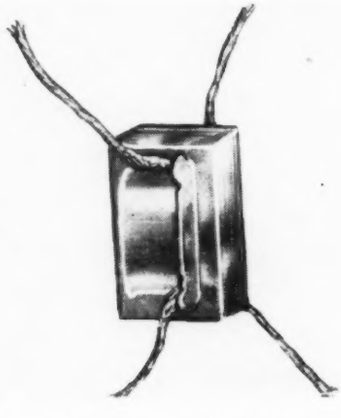
Marion Electrical Instrument Co., Manchester, N. H.

Composed of a metallized boro-silicate glass V jewel which is induction soldered into place electronically, this bearing assembly replaces the conventional screw settings and jewels. The use of these bearing assemblies, simplifies production line procedure, eliminates tedious assembly operations and permits the jewels to be positioned with accuracy. By insuring a more secure fastening, the metallized jewel and induction soldering combination removes a potential source of instrument failure. The overall size of the bearing assembly is decreased, and fabrication is simplified.

Small Transformers

United Transformer Corp., 150 Varick St., New York 13, N. Y.

These small transformers are $\frac{9}{16}$ in. x $\frac{5}{8}$ in. x $\frac{7}{8}$ in. and weigh only $\frac{1}{3}$ ounce. The coil is uniform layer-wound Formax wire on a

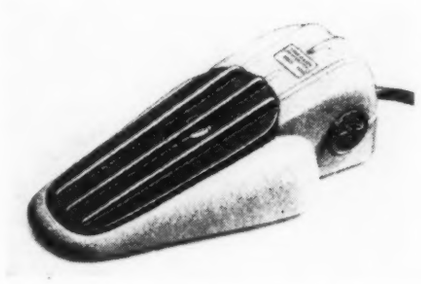


molded nylon bobbin with cellulose acetate insulation. The leads are mechanically anchored externally. The core material is Hipermalloy and the entire unit is sealed.

Foot Switch

Industrial Timer Corp., 117 Edison Pl., Newark 5, N. J.

A neon pilot light on this pedal, inside the switch illuminates the pedal in the dark. It operates on any a.c. circuit, and has a heavy duty snap-action, single pole, double throw switch. Silver contacts are used throughout. Two outlets, each with 1,500 watt capacity, operate electrical equipment when



pedal is depressed. One outlet (1,500 watt capacity) turns electric equipment off when pedal is depressed. The switch is claimed to operate with a minimum of noise.

Ball Bearings

Miniature Precision Bearings, Keene, N. H.

A series of miniature ball bearings available with outside diameter of $\frac{7}{16}$ in. and bores of $\frac{3}{32}$ in., $\frac{3}{16}$ in., $\frac{5}{32}$ in. and $\frac{1}{8}$ in. The bearings are manufactured of chrome bearing steel and finished to precision tolerances of +0.0000—0.0002 in. Designed for use in small motors, computers, electronic equipment, drive movements of recording devices, testing and laboratory equipment and supporting the moving parts of various precision mechanisms.

Automatic Flow Regulator

Waterman Engineering Co., 721 Custer Ave., Evanston, Ill.

Available in all pipe sizes, this hydraulic flow regulator gives unlimited flow in one direction and pre-determined rate of flow in the opposite direction. Hydraulic ma-

chine tools and lift devices can be controlled to predetermined speeds and insured against the sudden release of hydraulic pressure.

Temperature Indicating Alloy

General Electric Co., Schenectady 5, N. Y.

This alloy, a chrome cobalt composition, shows a marked color change for every 25 degree change in temperature from 500 deg. C. to 700 deg. C., then reverts to its original color and begins the color scale over again in a higher range of from 725 deg. to 900 deg. C. (1,652 deg. F.) Interference colors of the alloy change as the thickness of the oxide film changes, until the oxide film becomes so thick or irregular that no

color is transmitted through it to be reflected. At this point, indicated by a dull grey surface, oxidation has run its gamut of colors, and the metal is no longer useful for measuring temperature.

Operational Recorder

Ess Instrument Co., Bergenfield, N. J.

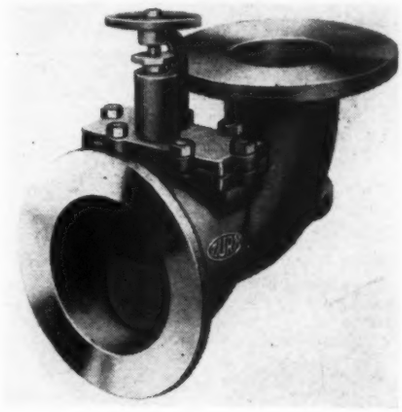
This instrument can be provided with a single acting pen, two position double acting pen or a three position pen. As many as six single or double acting pens can be combined on a single chart. It can be supplied in 115 to 230 volts a.c. or with special voltages on application. Clock mechanisms (a.c.) are available from 15 minute periods to 8 days. When operation is normal a circle is

traced. If the process goes too far in one direction, the pen moves outward and remains there until "normal" is resumed when the pen returns to the center point. If the process goes too far in the other direction the pen moves to the other side of "normal" and remains there as long as the conditions persist. Six of these three position "Normality" pens can be placed on one chart to give a complete picture of the "Normality" of six processes.

Discharge Check Valve

J. A. Zurn Mfg. Co., Erie, Pa.

These units have a swing check flap suspended from a full floating pin fulcrum to insure full surface contact between ground face of flap and flap seat. The knob in the center of the top surface of the swing check flap contact the valve body roof at one point when the swing check flap is wide open. This prevents the swing check flap from touching the sides of the valve body. Location of swing check flap in relation to interior of valve body provides protection against sediment blocking of the valve. Swing check flap suspended from cover can be removed, and replaced. Discharge check



valves can be operated with or without a manual control or with an extension shaft or flexible cable from an access box. The units are hydrostatically tested. Flanges are 150 lb. flat faced and blank or drilled as specified. They are available with 180 deg.; 105 deg. or 90 deg. bodies made of cast bronze, steel, semi-steel, cast iron and alloyed metals for corrosion resistance.

Flexible Plastic Tubing

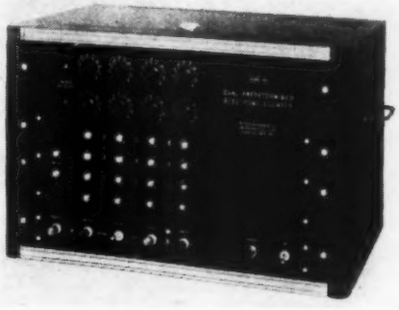
Irvington Varnish & Insulator Co., Irvington, N. J.

"Fibron" has the ability to withstand varnish treatment and baking operations without stiffening, even in applications where extreme operating temperatures are encountered. It is resistant to strong acids and alkalies, denatured alcohol, petroleum and its products, and coal tar solvents. It is claimed that the tubing has performed satisfactorily in instances where high dielectric and tensile strengths are important.

Electronic Counter

Potter Instrument Co., 136-56 Roosevelt Ave., Flushing, N. Y.

This instrument utilizes four standard Potter 4-tube counter-decade circuits. These decades give two independent predetermining channels in which any number from 0 to 10,000 may be initially set up by the rotary switches on the front panel. During the operation of the equipment, each channel is alternately preset to the desired predetermined number. This is accomplished

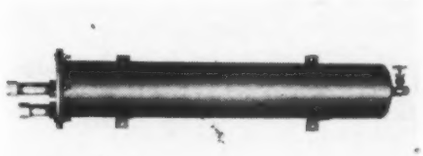


automatically by self-contained circuits. The input is arranged for operation with either make-contacts or with sharp negative pulses, as specified. Input frequencies may be in excess of 1,000 cycles per second. The output consists of an ultra high speed relay with single pole double throw contacts. This relay is energized at the end of one predetermined count cycle and remains energized throughout the other predetermined count cycle. Power for operation is obtained from a 110 volt 60 cycle circuit. Units are available for any specified total count with either the single or dual predetermining channels.

Chemical and Mechanical Dryers

The Gasflux Company, Mansfield, Ohio

The "636" Series Dryer has an outer shell of 6-in. O.D. seamless steel tubing and a removable inner shell or cartridge of rolled sheet metal having a perforated metal bot-



tom. A cast bronze head with inlet and outlet openings is bolted to a flange welded to the outer shell. Incoming gas or air passes downward between the inner and outer shell, trapping out entrained moisture, and then passes upward through the drying medium the full length of the cartridge in order to reach the outlet valve. Depending upon the drying efficiency that is required there is a choice of three drying media to be used in the cartridge, Fiberglas, calcium chloride and activated alumina.

Color Parkerizing

Parker Rust Proof Company

A chemical immersion process that imparts colors to Parkerized iron and steel surfaces, and increases the corrosion resistance of the coating. Color Parkerizing is a complex phosphate coating which is integral with the surface of the metal, is insoluble in water, does not smudge, chip or peel, and retards the spread of corrosion from any abraded areas. The coating does not cause any appreciable build-up over ordinary Parkerizing, and it may be applied to threaded articles or to assembly parts on which Parkerizing is commonly used. Color Parkerizing is applied by immersion and uses no electric current. Complicated shapes and parts with threaded members and holes are coated equally as well as flat surfaces. The coating results from chemical reaction. It is uniform, and there is no possibility of drips or tears. Complete coverage is assured as the chemical solution easily reaches all cavities and depressions.

NEW BOOKS

Relay Engineering

CHARLES A. PACKARD, 640 *pages*, 4½ *in.* x 7 *in., black fabricoid flexible covers. Published by Struthers-Dunn, Inc., Philadelphia, Pa. Price* $3.

A reference handbook containing, in addition to fundamental principles, a complete explanation of the equipment and circuits ordinarily encountered in the application of relays to modern electrical and electronic uses. One section is devoted to the servicing and inspection of relays and others cover the selection and installation of typical relays, relay components, and auxiliary equipment. Although a number of examples based on the use of Struthers-Dunn products are included, the book is generalized enough to be of use when dealing with relays of almost any manufacture.

Electronics for Engineers

JOHN MARCUS AND VIN ZELOFF, *Associate Editors, "Electronics". First edition,* 390 *pages,* 9 x 11¼ *in., blue clothboard covers. Published by McGraw-Hill Book Co.,* 330 *West* 42d *St., New York* 18, *N. Y. Price* $6.

A collection of 142 articles, reference sheets, charts and graphs for design engineers, builders, and users of electronic equipment and component parts, reprinted in convenient form from the pages of "Electronics." This material represents condensed information in graph and chart form which has been in great demand for the reference use of engineers engaged in designing circuits, equipment and individual parts for radio, electronic, television, facsimile, radar, sound and related vacuum-tube apparatus. The articles and accompanying charts and graphs, are arranged in groups, with complete cross-indexing. There are twenty-seven general subjects discussed, including: A-F impedance matching networks, antennas, electronic heating, relays, television, sound, tubes, and tuned circuits.

Mechanics for Engineers

EDWARD R. MAURER, RAYMOND J. ROARK AND GEORGE W. WASHA. 425 *pages,* 5¾ x 8¾ *in., green clothboard covers. Published by John Wiley & Sons,* 440 *4th Ave., New York* 16, *N. Y. Price* $4.

This is a textbook on theoretical mechanics for students of engineering. It is the outgrowth of repeated revisions of "Technical Mechanics," a textbook of long standing. The essential principles of theoretical mechanics are covered, together with their application to engineering problems. Among topics included are vector analysis, non-coplaner forces, plane and relative motion, d'Alembert's principle, virtual work and mechanical vibrations.

Many changes appear in the new volume: In statics, more attention is given to problems that involve coplanar forces. In dynamics, kinematics and kinetics are treated concurrently instead of separately. The force-acceleration relationship is introduced earlier, lending reality to concepts that might otherwise seem more mathematical abstractions. The methods of vector analysis are used more generally, in the discussion of curvilinear motion of a particle and of spherical and general motion of a rigid body. Plane motion and relative motion are dealt with more extensively, and d'Alembert's principle receives greater emphasis in view of the increasing importance of such subjects as engine balancing and dynamic stress.

Electronics Dictionary

NELSON M. COOKE, *Lieut, Comdr., Naval Research Laboratory, and* JOHN MARCUS, *Associate Editor, "Electronics." First edition,* 433 *pages,* 5½x8¾ *in.,* 600 *illustrations, red clothboard covers. Published by McGraw-Hill Book Co.,* 330 *West* 42nd *St., New York* 18, *N. Y. Price* $5.

A well illustrated glossary of nearly 6,500 terms used in radio, television, industrial electronics, communication, facsimile, sound recording, and the like. The more than 600 diagrams and sketches add to the book's usefulness.

The book is written primarily at the level of a student who is learning fundamental electronic principals, but effort has been made to define the terms with the accuracy and carefulness demanded by the engineer. Most of the definitions will have useful meanings to non-technical readers because each definition has been made as complete as possible.

Technical Data on Plastics

Published by Plastics Materials Mfrs. Assn., 14th and K Sts., N. W. Washington 5, *D. C.* 163 *pages,* 8½x11 *in., green paper covers. Price* $1.50.

This is a compilation of technical data whose purpose is to acquaint its user with the nature, particular merits and utility of various plastics. Physical and chemical properties of the available forms and modifications of the basic compositions, as measured by recognized methods, are listed in many charts. For simplification, individual materials very similar in composition and properties have been considered as members of groups for which data are given. In addition to property charts, general characteristics are described and manufacturers' names and addresses are given.

Practical Design for Arc Welding—Volume 3

ROBERT E. KINKEAD. 200 *pages,* 8½x11 *in., grey clothboard covers. Published by The Hobart Brothers, Troy, Ohio. Price* $3.50.

This volume is the third and final volume of the Hobart welding design series and continues the graphical presentation used in the previous volumes. Subject matter can be divided into five sections of twenty pages. The first section shows welded design used in a 15-ton dump truck. The second section shows common faults in welded design. The third section shows the use of welding to add a hard faced section to different types of parts. The fourth section compares complex modern designs with those of nature. The fifth section shows twenty typical patents granted to the welding process.

Internal Combustion Engines

V. L. MALEEV, 636 *pages,* 5x8¼ *in., green clothboard covers. Published by McGraw-Hill Publishing Co.,* 330 *West* 42nd *St., New York* 18, *N. Y. Price* $5.

Higher engine speed and greater engine output are characteristic changes that have taken place in internal combustion engine design since the writing of the original edition of this book twelve years ago. This second edition includes more material in respect to theory and recent research. Suggestions received from instructors using the original edition have resulted in the strengthening of the chapters devoted to design.

Electric Circuits and Machines

EUGENE C. LISTER, *former Supervisor of Electrical Theory Instruction, Specialized Training Program, Iowa State College. First edition,* 358 *pages,* 5¼x8¼ *in.,* 17 *chapters, blue clothboard covers. Published by McGraw-Hill Book Co.,* 330 *West* 42nd *St., New York* 18, *N. Y. Price* $3.50.

This textbook is an introduction to practical electricity and stresses fundamental principles of both direct and alternating current circuits and machines. The treatment is as non-mathematical as practicable, and the mathematics are limited largely to simple algebra. Many numerical examples are worked out in detail, and a list of problems is included in the chapters where the solution of problems will illustrate the application of the principles involved.

Ball and Roller Bearing Engineering

ARVID PALMGREN, *translated by Gunnar Palmgren and Bryce Ruley.* 270 *pages,* 7½x10 *in., blue, cloth-bound covers. Published by SKF Industries, Inc., Philadelphia, Pa. Price* $1.75.

A fundamental text on all phases of bearing applications containing over 900 drawings and tables. The book begins with a technical description of common bearing types and includes nine chapters of fundamental engineering studies. Both radial and thrust bearings are discussed comprehensively in Chapter I together with data on dimensional proportions, running accuracy and tolerances of each type. "Forces and Motions in Bearings," the second chapter, is devoted to theory and calculations on rolling resistance, friction torque, friction coefficients, stresses and deformations, load distribution, motion and inertia. Other chapters deal with carrying capacity of ball and roller bearings, bearing selection, design of bearing applications, mounting and dismounting, lubrication and maintenance and bearing failures. The final chapter is made up of tables, conversion values and a description of symbols and abbreviations.

Charts for Fluid Friction Bearing Design—I

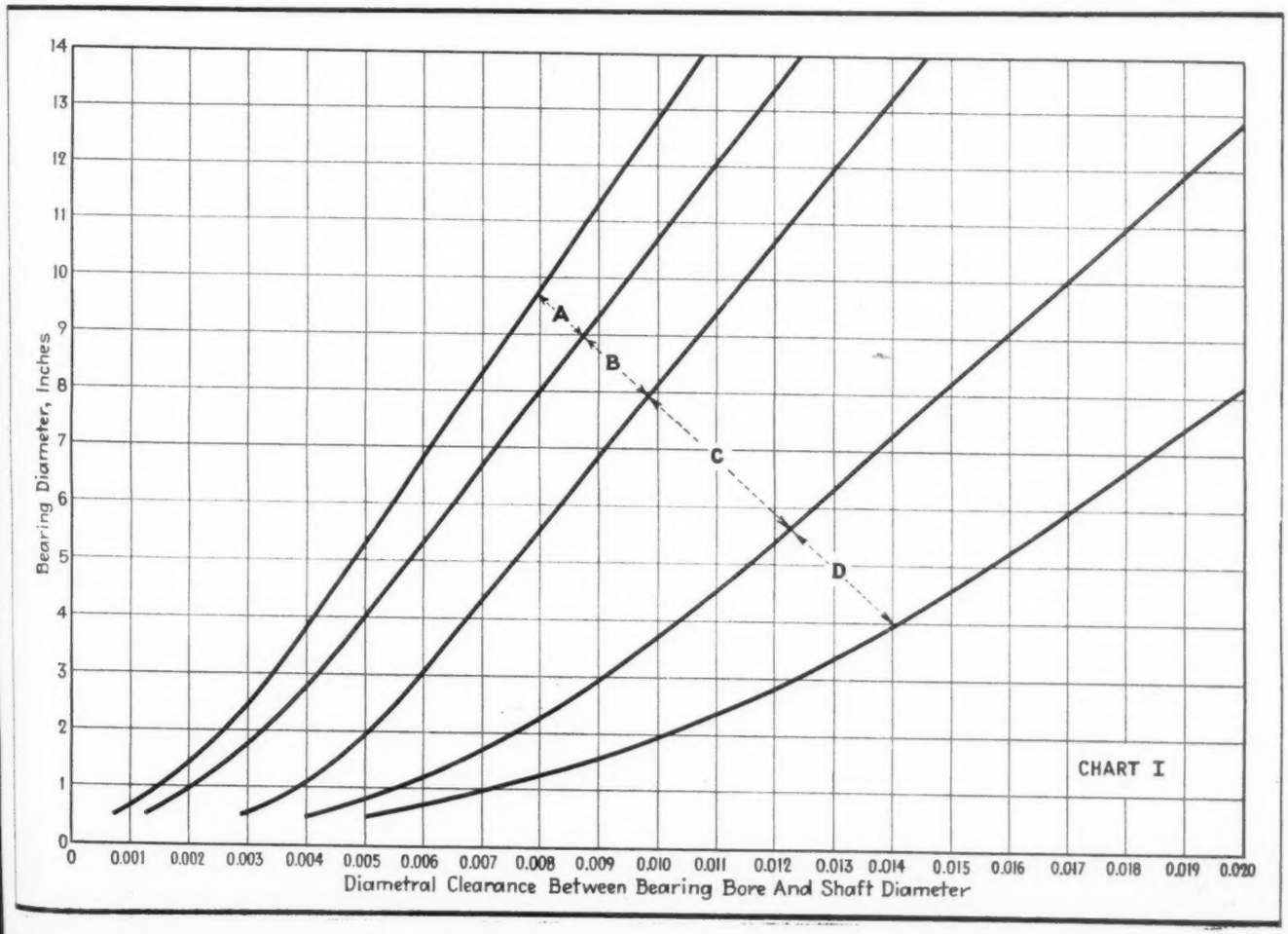
H. W. HAMM

THESE CHARTS have been constructed primarily as an aid in the design of bearings operating under fluid friction.

In Chart I, the recommended bearing clearance is obtained by a plot of the bearing diameter in inches against the diametral clearance in inches between the bearing bore and the shaft diameter. The portions of the chart designated as *A*, *B*, *C*, and *D* are the recommended clearance ranges for certain specific applications, where:

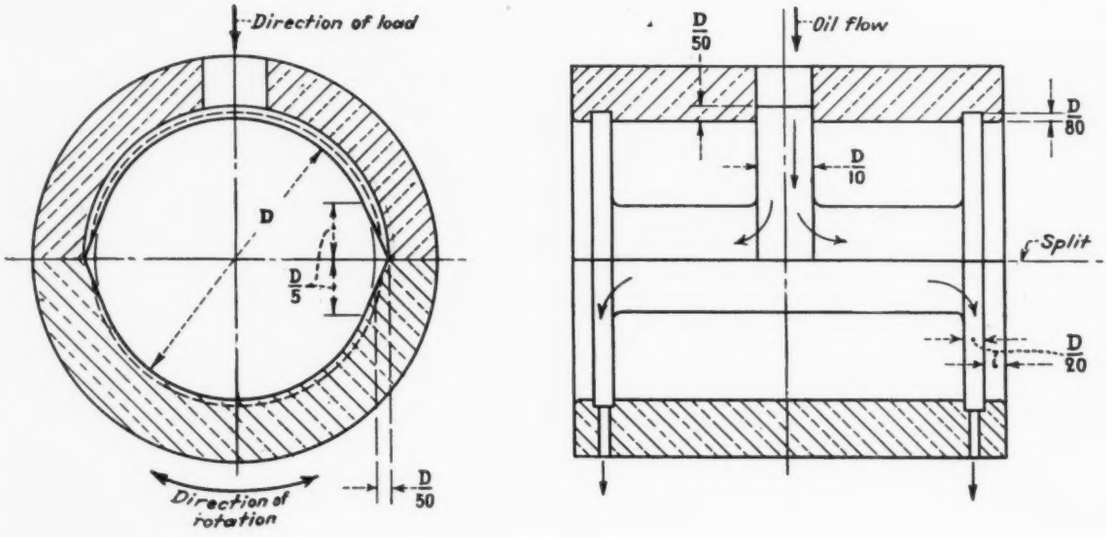
A = recommended range for precision spindle practice
B = recommended range for electric motor and generator practice
C = recommended range for general machine practice
D = recommended range for rough mill practice

The sketches accompanying this chart illustrate typical oil grooving for fluid friction bearings of the split and solid bushing type. All dimensions are in terms of *D*, the internal bearing diameter or bore, and directions of loading and rotation are given.

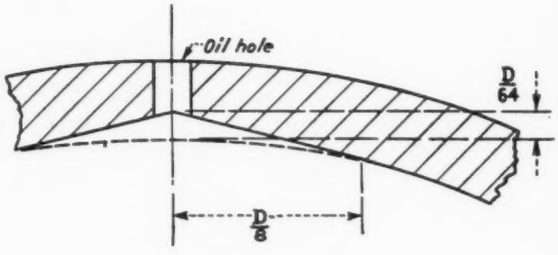


Charts for Fluid Friction Bearing Design (continued)

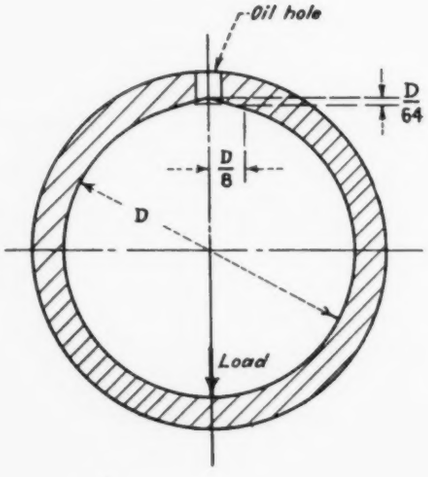
TYPICAL OIL GROOVING FOR FLUID FRICTION BEARINGS

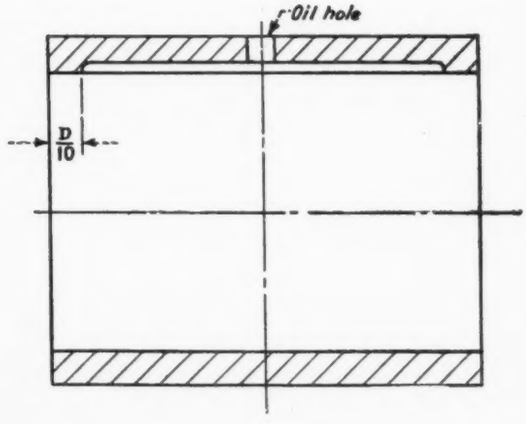


SPLIT BUSHING



SOLID BUSHING





PRODUCT ENGINEERING — REFERENCE BOOK SHEET